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AMERICAN ASSOCIATION

OF

PETROLEUM GEOLOGISTS

MARCH—APRIL 1921

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NOTES ON THE SUB-SURFACE PRE-PENNSYLVANIAN STRATIGRAPHY OF THE NORTHERN MID CONTINENT OIL FIELDS

By F. L. Aurin, G. C. Clark and E. A. Trager.

INTRODUCTION

GENERAL STATEMENT

Nearly all of the petroleum and natural gas produced in northern Oklahoma and Kansas prior to 1914 was obtained from formations of Pennsylvanian age. Until a few years ago wells were considered completed when the drill penetrated the upper strata of the so-called "Mississippi lime" because it was thought that all chances for producing oil had been exhausted when this horizon was reached. Few wells at that time were drilled very far into the Mississippian, and scarely any had penetrated it. Those that did penetrate it failed to show encouraging results and operators and geologists should not therefore be censured for unfavorable views relative to the possibility of petroleum production from the Mississippi lime.

About seven years ago, or possibly a little earlier, quantities of oil and gas were encountered in the top of the Mississippi lime, in Washington, Osage, and Tulsa counties, Oklahoma, and in Chautauqua and Montgomery counties, Kansas. During 1914, 1915 and 1916 new pools were discovered in the Mississippi lime and even below it, but the geologic age of these producing formations were not recognized as pre-Pennsylvanian

at that time and were assigned in most cases to the basal Pennsylvanian. Among the important discoveries of this period were the Blackwell field in Kay county and various other fields in Osage county, Oklahoma and the Augusta and Eldorado fields of Kansas. During 1917 and 1918 the Elbing and Peabody fields of Kansas and various isolated fields in Osage county, Oklahoma, in which the important producing horizons are thought by the writers to be of pre-Pennsylvanian age, were discovered.

In 1919 and 1920 deeper drilling was extensively resorted to and the results attained are of far reaching importance in the production of oil in the Mid Continent region. The most important discoveries in Oklahoma were the well known "Wilcox" sand[1] of Okmulgee and Creek counties, the Marland sand of the Ponca field, and the so-called "second break in the Mississippi lime" in Osage county. In Kansas the Covert-Sellers, Florence, and Elk county fields were the most notable new contributors.

As a consequence of these important discoveries the former views concerning the Mississippi lime have been materially changed and many wells are now started with the intention of drilling through the entire thickness of the Mississippi lime if oil or gas is not found at lesser depths. It would be interesting to cite the names and number of fields in the northern part of the Mid Continent region in which oil is produced from pre-Pennsylvanian formations and the relationship between this production and the total yield from all horizons, but unfortunately such information is not available.

The Marland Refining Company, after its discovery of the Marland sand in the Ponca field in 1919 undertook an investigation of this deep sand in Kay county and adjacent areas in Oklahoma and Kansas. One of the principal problems was to determine when wells, drilled for this deep production, had reached or penetrated the proper horizon, in order that they might not be abandoned prematurely or drilled into water sand; and to determine further, the point at which all possi-

[1]The name Wilcox as applied to a geologic sedimentary unit is preoccupied. Wherever used in this paper the term refers to the common local application of the name in Oklahoma.

bilities of deeper production were exhausted. From an economic standpoint it was a very practical investigation. On account of the many peculiarities in the basal Pennsylvanian, Mississippi lime, and underlying sediments, the driller's log could not be sufficiently relied upon, and accordingly it was necessary to devise a better method of approach. The plan consisted essentially of the assembly of logs of wells drilled to the Mississippi lime or deeper, the careful collection of well cuttings from as many wells as possible and the physical analysis, preparation of thin sections, and detailed microscopic examination of these cuttings. Another phase of the work was the preparation of the usual stratigraphic cross sections based on well logs and supplemented by data obtained from the examination of well cuttings. It was also planned to collect samples of water encountered in the pre-Pennsylvanian for future study. The investigation had not long been in progress before the Geological Department of the Marland Refining Company was enabled to furnish valuable information to the management. The local problem was interesting from the start and furnished an incentive to extend the study to other places in northern Oklahoma and Kansas. Some field work was done in the examination of outcrops of the basal Pennsylvanian, Mississippian, Devonian, and Ordovician in eastern Oklahoma. Specimens of these formations were collected for comparative study with the cuttings from the deeper sub-surface horizons to the west.

SCOPE OF PAPER

The results of the recent investigation for the Marland Company are presented in this paper. The previous literature on the subject includes a paper presented at the last meeting of the American Association of Petroleum Geologists by one of the joint authors[2], an article on the "Wilcox" sand of the Okmulgee district by F. C. Greene[3], and a paper by L. H. White on the correlation of the "Wilcox" sand with the second break in the Mississippi lime of Osage county, Oklahoma, presented before the Tulsa Geological Society.

The present paper comprises a discussion of the correlation

[2]Aurin, F. L., Pre-Pennsylvanian Oil and Gas Horizons in Kay county, Oklahoma, Bull. Amer. Assn. Petroleum Geol., Vol. 4, No. 2, 1920.
[3]Greene, F. C., Oil and Gas Jour., Vol 18, pp. 54-56, 1920.

of the pre-Pennsylvanian stratigraphy in the Okmulgee, Bristow, Yale, Osage and Kay county districts of Oklahoma, and the Augusta, Elbing, Peabody, Florence and other districts of Kansas. The territory included is so large that much interesting data had necessarily to be omitted. Cuttings from wells were obtained in practically all of the areas and the conclusions reached are not based on logs alone. The following cross sections were made from the data on deep wells which were available: Muskogee to Okmulgee; Okmulgee to Glenn pool and southern Osage county; Sinclair to Okmulgee; Okmulgee northwest to Bristow; Jennings northeast to the Boston pool, Osage county; Boston pool northwest to the Ponca City field; Ponca City northeastward to Cowley county, Kansas and northward to Douglass, Augusta, ElDorado, Elbing, Peabody, Covert-Sellars, and Florence; and then north and northwest for a short distance. Other cross sections were made between Cushing and the Glenn pool, and eastward to within a few miles of the outcrop of the Mississippian. The cross sections included in this paper are generalized, but were compiled from cross sections of actual individual well logs. A few of the important horizons of the Pennsylvanian are also shown, but no attempt is made to present a detailed discussion of them. Various deep wells in areas other than those located near the cross sections are mentioned, but no pretense of completeness is made. The field is new and later additional data may modify some of the tentative conclusions. However, the purpose of the authors will have been fulfilled if it encourages more interest in the problem. It is hoped that those who do not agree with the interpretations will present additional data and thus add to the common fund of knowledge of the general stratigraphic positions of some of the deep oil and gas horizons.

ACKNOWLEDGMENT

Special acknowledgment is due to the Marland Refining Company for permission to present this paper. It was principally through the deep interest of Mr. E. W. Marland, president, Mr. F. P. Geyer, chief geologist, and other officers of this company that the work was encouraged and made possible. Other oil companies, especially the Roxana Petroleum Cor-

poration and the Empire Gas and Fuel Company, as well as the Oklahoma Geological Survey cooperated by the exchange of data and samples of well cuttings. The field men in the Geological Department sub-surface branch of the Marland Refining Company rendered efficient service in the collection of data. Others who assisted are Stuart E. Clark, M. G. Hoffman, E. C. Parker, J. I. Daniels and I. E. Dugan. The writers wish to emphasize the fact that these data presented are not results achieved by any individual but that the geological department as a whole should receive any credit due.

DESCRIPTION OF FORMATIONS

PRE-PENNSYLVANIAN ROCKS

The description of subsurface conditions and the discussion of pre-Pennsylvanian stratigraphy in the northern Mid-Continent oil and gas fields, may be desirably prefaced in brief notes concerning these formations at the outcrops in northeastern Oklahoma. Attempt is then made to trace them along the line of the selected cross sections. The following Pre-Pennsylvanian surface formations[4] are found at the surface; Unnamed Cambro-Ordovician limestone; Burgen sandstone and Tyner formations of Ordovician age; St. Clair marble of Silurian age; Chattanooga shale of Devonian or basal Mississippian age; and Boone chert, Mayes limestone, Fayetteville formation and Pitkin limestone of Mississippian age. The Pennsylvanian formations include the Morrow and Winslow or Cherokee shale, according to the locality.

The only igneous rock exposed is at Spavinaw, Mayes county, Oklahoma. It is not an igneous dike as is generally thought but a granite peak of the old pre-Cambrian basement. Overlying the granite is a siliceous dolomitic limestone several hundred feet in thickness, correlated with similar limestones of Cambro-Ordovician age in other localities. The upper part of this formation contains considerable chert breccia. Some hydrogen sulphide or so-called sulphur springs were noted on the surface.

The Burgen sandstone consists of massive white and brown, soft, friable material. It is thought to be of only local occur-

[4]Discussed in full by L. C. Snider, Okla. Geol. Survey, Bull. 24.

rence and is correlated with the St. Peter sandstone by Taff.

The Tyner formation consists of green and blue shales, calcareous and cherty sandstone, and limestone. The thickness is variable on account of an unconformity above it. There are only a few exposures of this formation in northeastern Oklahoma but from them it seems to be of widespread occurrence.

The St. Clair marble is a white and pinkish crystalline limestone and is correlated by Ulrich with the Niagaran of Silurian age. It is not of general occurrence very far north of Marble City, Sequoyah county, Oklahoma. The original limestone may have been deposited to the north but if so it was subsequently eroded, as there is an unconformity above it. It is also possible that this formation may not have been deposited in this area. The St. Clair marble is equivalent at least in part to the Chimneyhill member of the Hunton formation in the Arbuckle mountain region.

The Chattanooga shale, and the Sylamore sandstone at its base, are stratigraphically above the St. Clair marble. The Sylamore sandstone is commonly brown and of local occurrence. The Chattanooga is a black fissile shale which is widely distributed though absent locally because of the erosional unconformity above it. The thickness ranges up to 85 feet in known exposures. The age is considered to be Devonian by some, though others place it in the Mississippian.

The Boone formation or Boone chert as it is usually known, consists of several members and lies unconformably on the Chattanooga shale or lower horizons. Locally a small thickness of Kinderhook beds occurs at the base. There is an unconformity above the Kinderhook. The next succeeding member is the St. Joe limestone of variable thickness which is locally absent. The thickness ranges up to 100 feet. It is usually described as a light colored, evenly bedded, crinoidal limestone and has been correlated with the basal Burlington or Fern Glen of the Mississippian type section. The chert member which comprises the upper part of the Boone formation, consists of gray chert and limestone, usually in alternating beds. The thickness ranges from 25 to 300 feet. The age of this member is placed by Snider in the Burlington, Keokuk, and

lower Warsaw of the Mississippian type section. There is an unconformity above the Boone formation in Oklahoma representing most of Warsaw and all of Salem, St. Louis, and Ste. Genevieve time.

In northeastern Oklahoma the Mayes formation lies unconformably upon the Boone. It consists of gray to dark limestone and some shale beds, the total thickness ranging from a few feet to 100 feet. Its maximum thickness is attained in the Pryor quadrangle, but it is of general occurrence in this area. The Mayes is of Chester age.

The Fayetteville formation and Pitkin limestone, which are above the Mayes are also of Chester age, the former consisting principally of black shale and several thin limestone members and the latter of limestone. The thickness of the Fayetteville ranges from a few feet to as much as 125 feet, the average being about 60 feet, and the Pitkin from a few feet to 70 feet. Both the Fayetteville and Pitkin are widely distributed. Above the Pitkin there is an unconformity, slight in the southern part of the area, but representing a greater time interval in the northern part.

BASAL PENNSYLVANIAN ROCKS

The Pennsylvanian of northeastern Oklahoma includes the Morrow group at the base and the Winslow or Cherokee formations and succeeding divisions above. The Morrow is stratigraphically above the Pitkin and is in contact with it in the southern part of the area, while in the northern part it is in contact with lower beds. The Morrow consists of thinly bedded, platy limestone, dark shales, and some sandstone. There is a distinct unconformity above the Morrow. In the southern part of the area the Winslow formation is in contact with it and in the northern part the Cherokee shale. To the south lower Pennsylvanian rocks lie unconformably upon the Morrow, but to the north the Pennsylvanian gradually transgresses the lower formations and in extreme northeastern Oklahoma, the Cherokee rests unconformably on the Boone. The Cherokee shale, according to the literature, is correlated with the formations in east central Oklahoma from the base of the Atoka formation to the base of the Calvin sandstone. A few years ago the authors, together with W. R. Berger and D. K. Greger who

were engaged in stratigraphic work for the Empire Gas and Fuel Company in this area, correlated the base of the Cherokee with the basal part of the McAlester shale of the southern Oklahoma section.

Only that part of the Pennsylvinian below the Boggy shale will be discussed in this paper. In this there is an unconformity at the top of the Morrow group, another several hundred feet above, and still another at the base of the Boggy. A massive sandstone more than 100 feet thick rests upon the Morrow and above this occurs a series of black shales and gray to black siliceous sandstones. The thickness of the latter ranges from about 200 to 400 feet and above it there is an erosional and structural unconformity. In most places a thinly bedded, ripple-marked brown quartzitic sandstone is found above the break, the sandstone being succeeded by about 350 feet of shales, several thin beds of sandstone, and a thin bed of coal. The top of the series is capped by a thick bed of massive sandstone, which from field examinations to the north may be correlated with a massive bed of sandstone about 200 feet above the base of the Cherokee shale in a section west of Pryor, Oklahoma. The interval between a massive sandstone in the basal part of the Boggy shale and the last mentioned sandstone is roughly 400 feet and consists principally of shale with several thin beds of sandstone and a bed of coal near the base. There is an unconformity approximately at the position of the base of the Boggy shale (as defined by Taff in the Muskogee folio.)

According to surface sections wells drilled in the vicinity of Muskogee should encounter the Mississippian at comparatively shallow depths, but it is found at considerably greater depths than expected. Another peculiar feature is that at the western margin of the Mississippian outcrops east of Muskogee the interval between surface horizons in the Pennsylvanian (excluding the Morrow group and the Mississippian) is much greater in the general areas in alignment with the synclines than is shown in the surface sections or in the areas in alignment with the anticlines. Even in the latter case the intervals are greater than shown by the surface sections. This fea-

ture will be discussed in connection with the cross section between Muskogee and Okmulgee.

PRE-PENNSYLVANIAN PRODUCING AREAS

OKMULGEE-MUSKOGEE DISTRICT

General Description

The preparation of a cross section between the outcrop of the Mississippian east of Muskogee and the typical Wilcox producing district near Okmulgee is very difficult on account of the change in the basal Pennsylvanian mentioned and the scarcity of reliable logs of wells that have been drilled deep enough to penetrate the Mississippian. In order to include a large number of horizons it was necessary to select a zigzag course in a general westerly direction across a strip of territory eight to ten miles in width north and south. The cross section starts at the well drilled at Fort Gibson near the outcrop of the Mississippian as reported by Taff in the Muskogee folio. Taff's correlation is as follows:

Fort Gibson Well

Depth	Thickness	Correlation
0- 800	800	No record
800- 830	30	Chattanooga shale
830- 892	62	St. Clair marble
892-1008	216	Tyner formation, red, blue and green shale, some ss-
1008-1088	80	Burgen sandstone
1088-1166	78	Limestone, light blue, magnesian, (Yellville of northern Arkansas)
1166		Total Depth

In going west from the Fort Gibson well all of the above formations can be recognized in the logs of the deep wells. A few miles southwest of Muskogee the following correlations were made of a well a few miles southwest of Muskogee:

Well Southwest of Muskogee

Depth	Thickness	Correlation
1590-1820	230	Pitkin and Morrow
1820-1910	90	Fayetteville shale
1910-2010	100	Sand (probably chert) Boone?
2010-2050	40	Chattanooga shale
2050-2310	260	Tyner formation, green and red shale and green ss.
2310-2390	80	Sandy limestone (Ordovician, probably equivalent to Yellville limestone)
2390		Total Depth

It is very difficult to differentiate the Mayes limestone and Boone formation in the well logs, and these two formations will therefore be referred to as the Mayes-Boone formations or Mississippi lime. Above the Pitkin and Morrow beds most of the logs record a number of thin black limestones which may be equivalent to the dark siliceous sandstones found in the lower part of the Pennsylvanian section above the Morrow east of Warner.

A considerable number of deep wells have been drilled in Ts. 14 and 15 N., Rs. 11, 12, 13, 14, 15, 16, 17 and 18 E., so that with a good start at Muskogee practically all of the above Mississippian and older formations can be correlated throughout the district in which the cross section was made. Though it is possible to describe these formations in all wells penetrating them, a brief discussion of the general conditions will be given, beginning with the basal Pennsylvanian. A massive sandstone near the top of the Winslow, which outcrops in the hills about 6 or 7 miles southwest of Muskogee can be traced westward beneath the surface to the Okmulgee district, where it is known as the Salt sand. This sandstone is the one previously referred to as equivalent to a sandstone about 200 feet above the base of the Cherokee shale west of Pryor, and which in turn may be equivalent to the Bartlesville sand. The Booch sand in the Okmulgee district seems to correspond to, or is approximately the stratigraphic equivalent of a sandstone outcropping a few miles south of Muskogee. Other horizons in the Pennsylvanian between these and the Mississippian will not be discussed here. The Pitkin-Morrow formations, which are not differentiated in this discussion, can be traced westward from the outcrop by deep wells across the area, but can be correlated only in the logs of such wells as have been drilled to the Mississippi lime or Tyner formation. The interval between the Pitkin-Morrow and the Salt sand changes considerably. The following approximate average intervals were noted along the township line between Ts. 14 and 15 N. Rs. 11 to 18 E., R. 18 E., 1,900 feet (interval between Salt sand and lower horizons projected); R. 17, E., 1,500 feet; R. 16 E., 1,400 feet; R. 15 E., 1,300 feet; R. 14 E., 1,100 feet; R. 13 E., 850 feet; R. 12 E., 700 feet; and R. 11 E., 550 feet. Though there are some local var-

iations in thickness, there are no marked changes in the Pitkin in this cross section, except that it is in general thinner westward. The Fayetteville shale maintains its identitiy in this area and is fairly constant in character and thickness. The Mississippi lime can also be correlated across this area. In some logs it is recorded as a cherty limestone, black limestone, or occasionally as black sand, and in some places it is apparently absent. In T. 14 N., R. 11 E., in the Okmulgee district, the Mississipian, which is known as the Black lime, is encountered at an average depth of 2500 feet, and is the first so-called Black lime above the "Wilcox" sand. The intervals between the top of the Pitkin-Morrow series and the top of the Black lime is fairly constant, being about 300 feet in T. 14 N., R. 18 E., and about 200 feet in T. 14 N., R. 11 E. The Black lime, which is a black shaly and sandy limestone, is possibly equivalent to the Mayes formation. There is a fossiliferous horizon in the lower part of the formation from which a few fragments of fossils were found by the writers in the cuttings at a depth of 2,921 feet, about 60 feet above the base of the Black lime, from a well drilled in sec. 19, T. 15 N., R. 11 E. One of the fossils was identified by Dr. Stuart Weller[5] as *Liorhynchus carboniferum*, a typical brachiopod of the Mayes formation.

The Chattanooga shale can be identified throughout the area of the cross section in the Okmulgee district by its stratigraphic position. It comprises the interval, usually about 50 feet, between the Black lime and the White lime or the "Wilcox" sand, as the case may be, and its character is practically the same as at the outcrop.

A limestone, somewhat variable in thickness, occurs locally below the Chattanooga shale in the area of this cross section. It directly overlies the "Wilcox" sand in the Okmulgee district and is known as the White lime. Its occurrence is fairly regular in some areas, while in others it is entirely absent. The White lime has the stratigraphic position of the St. Clair marble, but, it is thought to be lower than the St. Clair. Faunal evidence as to the stratigraphic position of this limestone is discussed in the summary.

[5]Personal communication.

The "Wilcox" or Mounds sand, as it is sometimes known, which is the most important producing horizon of late development in the Okmulgee district, is correlated with the Tyner formation. The "Wilcox" sand is immediately below the White lime, or below the Black shale (here called Chattanooga shale) in areas where the White lime is absent. The Tyner formation can be recognized more readily than any other pre-Pennsylvanian formation in all wells drilled to it in this area. The red, blue and green shales and sandstones which are characteristic of the Tyner are present in this formation to the west. Sandstones make up the principal part of the formation in the Okmulgee district, the uppermost bed of sandstone being the "Wilcox" sand in T. 14 N., R. 11 E., while the shales, usually green or red in color, are much thinner than to the east. The following average intervals between the Salt sand and the top of the Tyner formation or Mounds sand from east to west along the township line between Ts. 14 and 15 N., R. 11 to 18 E., are as follows: R. 18 E. (interval of Salt sand projected) 2,350 feet; R. 17 E., 2,050 feet; R. 16 E., 1,900 feet, R. 15 E. 1,750 feet; R. 14 E., 1,550 feet; R. 13 E., 1,300 feet; R. 12 E., 1,200 feet and R. 11 E., 1,100 feet.

The Ordovician siliceous limestone series, as exposed at Spavinaw above the granite and as identified by Taff[6] in the Fort Gibson well, is not traceable from Muskogee to Okmulgee, except in occasional widely separated wells. However, some of the deep wells in the latter area have penetrated this formation to a depth of about 700 feet. Examination of the well cuttings show that it has practically the same characteristics as are exposed at the surface.

From these data it would appear that the Mississippian and older formations which outcrop along the western margin of the Ozark uplift maintain their identity as far west as Okmulgee and that the conditions of deposition were similar in these areas. After the deposition of the Pitkin and Morrow sediments the Mississippian basement in the vicinity of Muskogee subsided to form a depressed area in which more of the lower Pennsylvanian sediments were deposited than either east or

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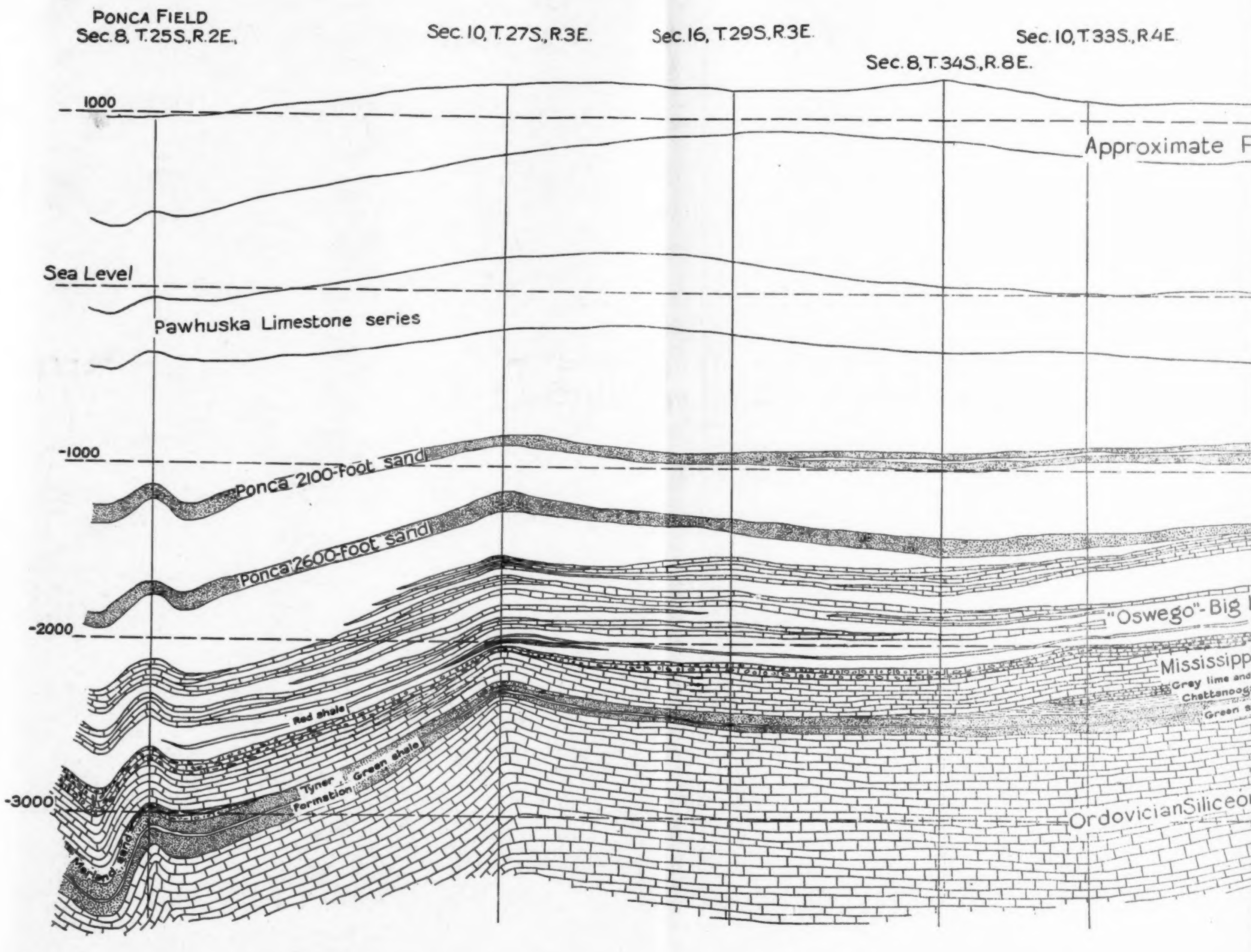
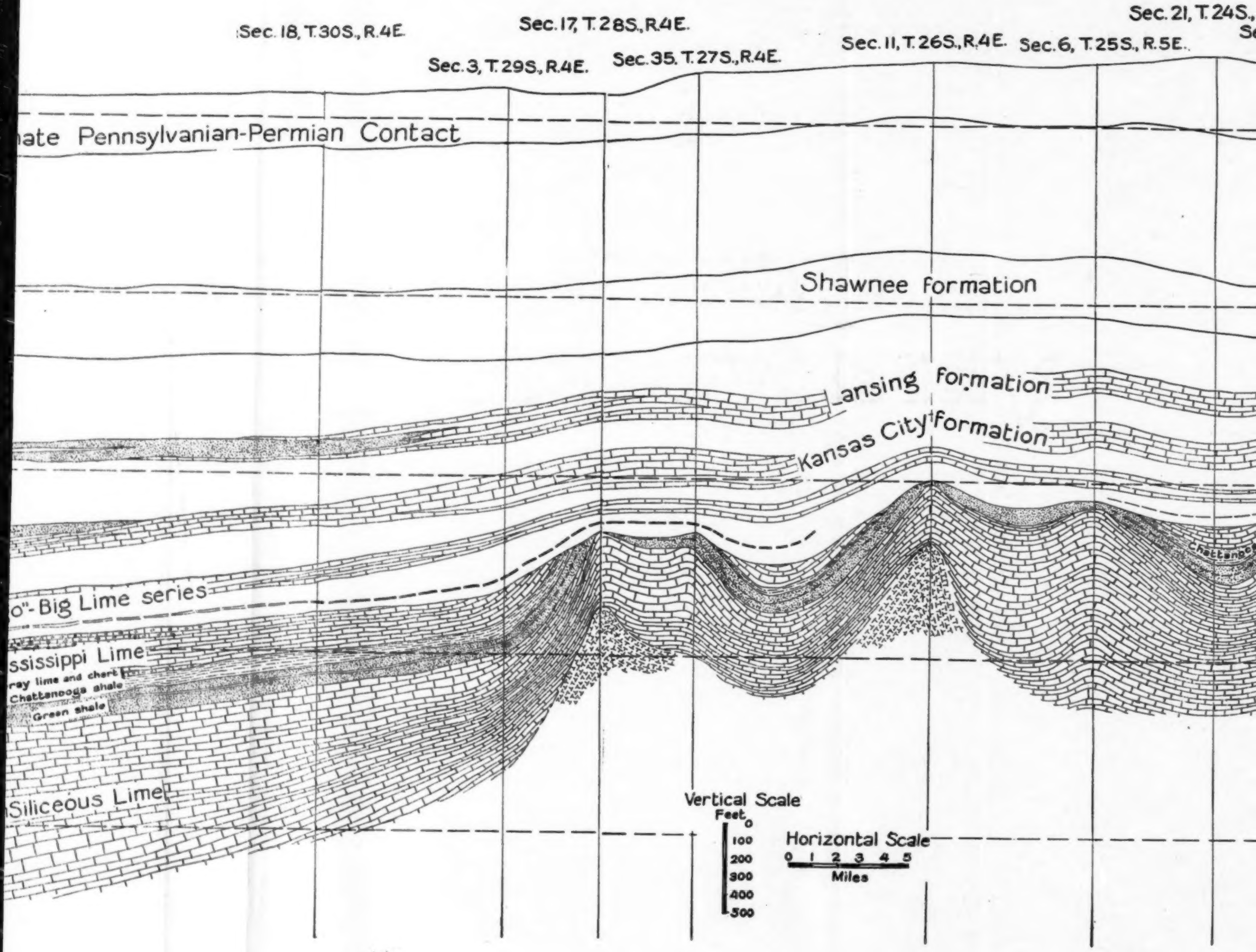
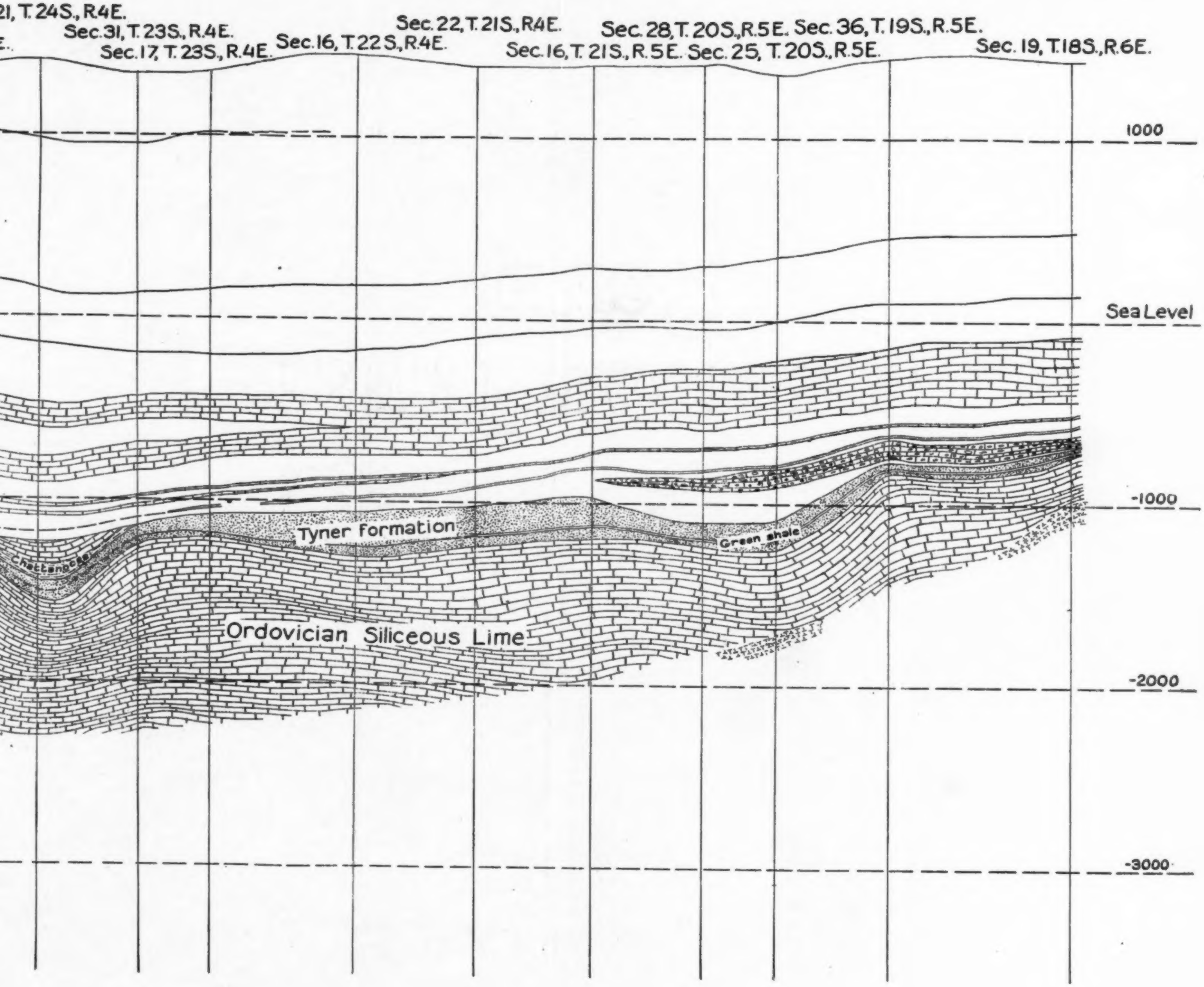
[6]Taff, J. A. U. S. Geol. Survey, Geologic folio 132.



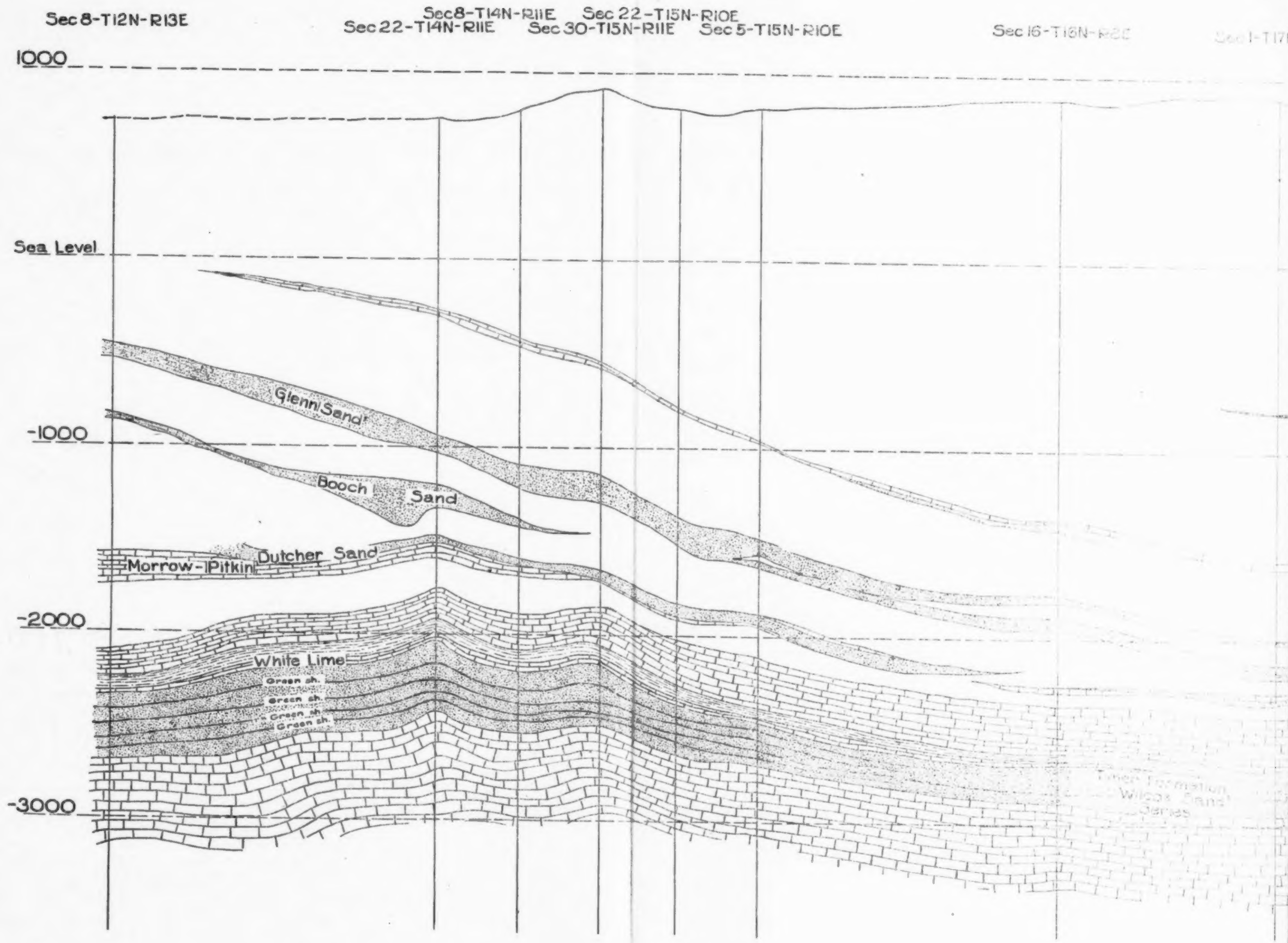
PONCA FIELD
Sec. 8, T. 25 S., R. 2 E.
Sec. 10, T. 27 S., R. 3 E.
Sec. 16, T. 29 S., R. 3 E.
Sec. 8, T. 34 S., R. 8 E.
Sec. 10, T. 33 S., R. 4 E.
1000
Approximate P
Sea Level
Pawhuska Limestone series
-1000
Ponca 2100-foot sand
Ponca 2600-foot sand
"Oswego"-Big L
-2000
Mississippi
Grey lime and
Chattanooga
Green sh
Red shale
Tyner Formation
Green shale
-3000
Ordovician Siliceou

GENERALIZED SECTION FROM
THE PONCA FIELD, OKLAHOMA
TO FLORENCE, KANSAS



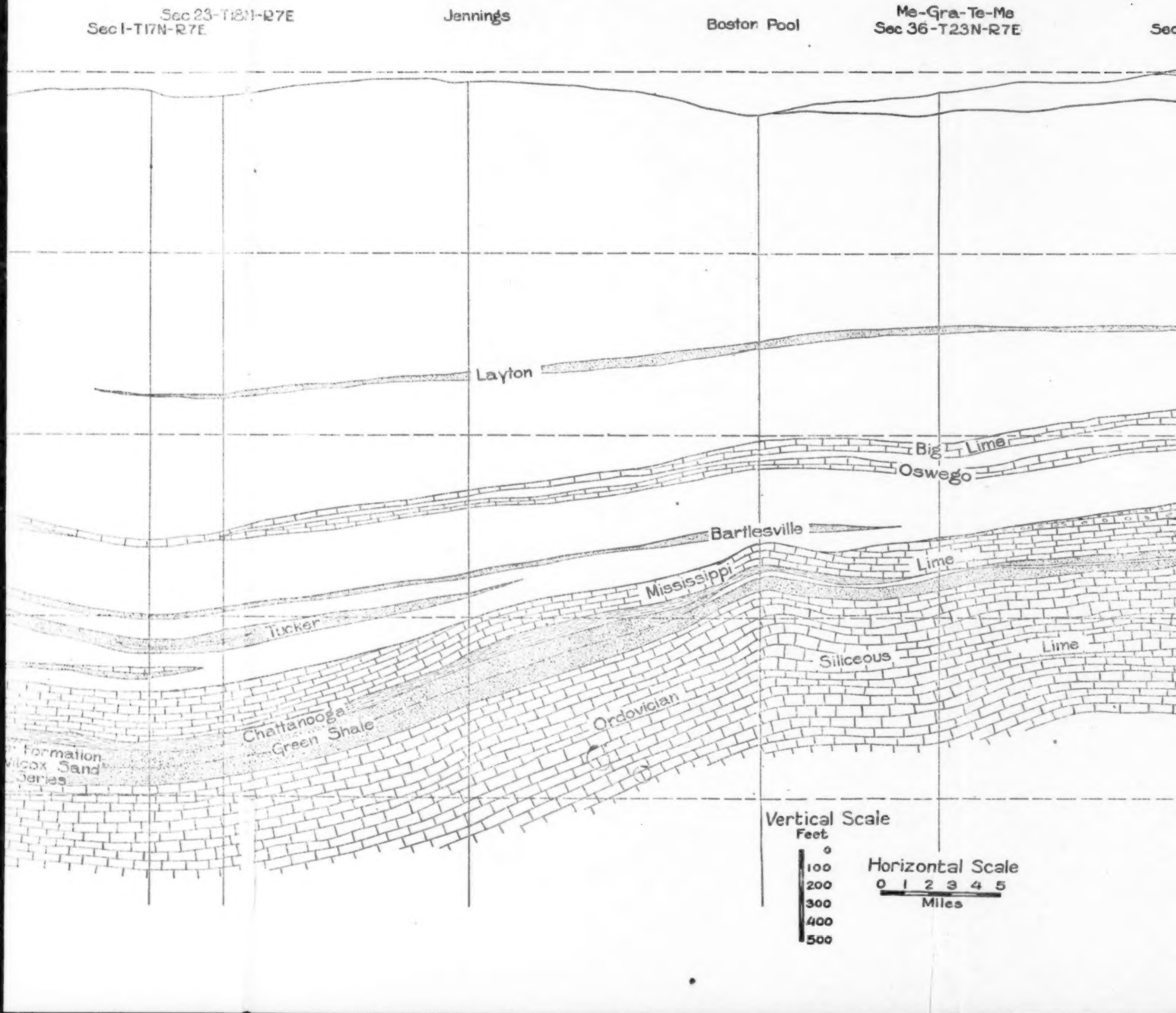


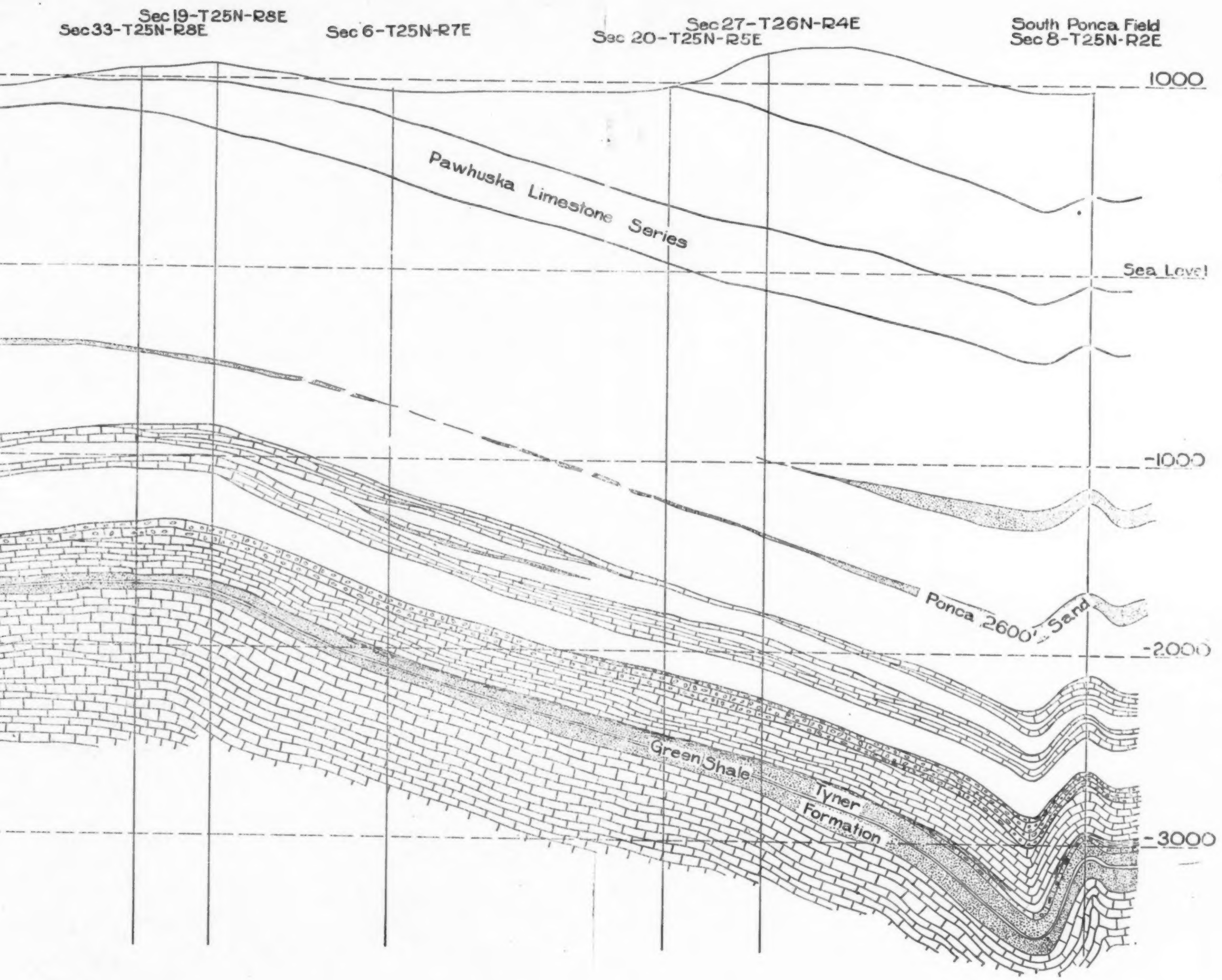
21, T. 24S., R.4E.
E.
Sec. 31, T. 23S., R.4E.
Sec. 17, T. 23S., R.4E.
Sec. 16, T. 22S., R.4E.
Sec. 22, T. 21S., R.4E.
Sec. 16, T. 21S., R.5E.
Sec. 28, T. 20S., R.5E.
Sec. 25, T. 20S., R.5E.
Sec. 36, T. 19S., R.5E.
Sec. 19, T. 18S., R.6E.
1000
Sea Level
-1000
-2000
-3000
Tyner formation
Green shale
Chattanooga
Ordovician Siliceous Lime



Sec 8-T12N-R13E
Sec8-T14N-R11E
Sec 22-T14N-R11E
Sec 22-T15N-R10E
Sec 30-T15N-R11E
Sec 5-T15N-R10E
Sec 16-T16N-R8E
1000
Sea Level
-1000
-2000
-3000
Glenn Sand
Booch Sand
Dutcher Sand
Morrow-Pitkin
White Lime
Green sh.
Green sh.
Green sh.
Green sh.

GENERALIZED SECTION
FROM OKMULGEE TO
THE PONCA FIELD, OKLAHOMA





Sec 19-T25N-R8E
Sec 33-T25N-R8E
Sec 6-T25N-R7E
Sec 27-T26N-R4E
Sec 20-T25N-R5E
South Ponca Field
Sec 8-T25N-R2E
1000
Pawhuska Limestone Series
Sea Level
-1000
Ponca 2600' Sand
-2000
Green Shale
Tyner
Formation
-3000

w
p
p
t

t
e
a
t
s
s
B
a
i
f
1,
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n
b
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c
w
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a
p
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s
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t
r
M
M

west of this place. This condition existed until the time just preceding the deposition of the Booch sand. Conditions were practically normal in both areas between the times of deposition of the Booch and Salt sands.

Area South of Okmulgee

A cross section was made from T. 14 N., R. 11 E., southward to T. 12 N., R. 11 E. From correlations of well logs and the examination of cuttings from a few wells the following notes are given . All of the Mississippian formations can be identified throughout this area. The principal change noted in the Mississippian is an increase in the thickness of the Fayetteville shale from about 150 feet in T. 13 N. to 340 feet in T. 12 N. The Black lime, or so-called Mississippi lime, contains more sand and shale to the south. From T. 14 N. to 12 N., R. 11 E., the intervals between the Salt sand and the Mounds sand are as follows: T. 14 N., 1,100 feet; T. 13 N., 1,300 feet; T. 12 N. 1,800 feet. It is reasonable to assume that the interval between these formations increases at least proportionately, if not more rapidly, south of T. 12 N., as the lower Pennsylvanian below the horizon of the Salt sand is exceptionally thick in that region.

Area North of Okmulgee

The following conclusions were reached from the study of a cross section from T. 14 N., to T. 20 N., R. 11 E., as revealed by well logs. The Mississippian and older formations are fairly uniform in character as far north as the Osage county line. The Salt sand is correlated with the Glenn sand and the Bartlesville, or is approximately equivalent to them. The Pitkin-Morrow and Fayetteville formations become thinner and disappear, probably on account of the overlap north of T. 16 N. The Black or Mississippi lime is practically the same in character and is slightly thicker to the north. In the Glenn pool area it is correlated with the black limestone which Carl D. Smith[7] tentatively correlated with the Pitkin-Morrow, but which is correlated by the writers with the Mayes or middle member of the Mississippi lime. The interval between the Salt sand and the Mississippi lime from south to north is as follows: T. 15 N., 800

[7]Smith, Carl D. U. S. Geol. Survey, Bull. 541-B, p 17, 1913.

feet; T. 16 N., 650 feet; T. 17 N., 500 feet; T. 18 N., 450 feet; T. 19 N., 350 feet. The Chattanooga shale and Tyner formation can also be identified in the Glenn pool where the latter is about 250 or 300 feet thick, the uppermost sandstone being approximately equivalent to the "Wilcox" or Mounds sand. The same characteristic features of the red and green shales and sandstone are present in the Tyner formation in the Glenn pool. The Ordovician siliceous limestone can also be identified in this area. It is the cherty limestone tentatively but probably erroneously correlated by Carl D. Smith[8] with the Boone.

The correlations in the area north of Okmulgee were confirmed by a cross section from the Glenn pool eastward through T. 18 N. to the outcrop of the pre-Pennsylvanian formations east of Wagoner. It is interesting to note that the Mississippi lime just east of the Glenn pool dips eastward for a few miles. This dip is not evident in the "Oswego" or Big lime. At this place a series of limestones, possibly equivalent to the Pitkin-Morrow, appears in the section to the east but disappears from it to the west. A corresponding condition exists south of the Glenn pool between secs. 15 and 5, T. 16 N., R. 11 E., at which point the Pitkin-Morrow series appears in the section to the south and disappears from it to the north. This feature suggests that the Glenn pool area is located above or at the edge of an elevated pre-Pennsylvanian plateau of some kind. The greatest interval between the "Oswego" lime and the Mississippi lime between Glenn pool and Wagoner is in T. 18 N., R. 13 E., where it amounts to approximately 1,350 feet.

BRISTOW-CUSHING-YALE DISTRICT

General Description

The correlations given in the Okmulgee district were confirmed by a cross section including correlations based upon well logs and cuttings to the Bristow-Cushing and Yale areas. The general cross section extends from T. 14 N., R. 11 E., in a general northwest direction through T. 15 N., R. 10 E., T. 15 N., R. 11 E., T. 16 N., R. 9 E., T. 16 N., R. 8 E., and the east side of Ts. 18, 19, 20 N., R. 7 E., to the Boston pool in Osage county. This cross section does not go through the main part

[8]Loc. cit.

of the Cushing field, but passes east of it. Another cross section was constructed across the area between the Cushing field and the Glenn pool. From the former it was extended to the Yale field. In order to check this extension the correlations were carried from the Cushing field northward to the Jennings field and then southwest to the Yale field. Another cross section was made from the Yale field north and northeast to the Boston pool in Osage county. Well cuttings were obtained from many wells in these areas. The interval between the Salt sand or Bartlesville sand and the top of the Mississippi lime decreases from about 800 feet in T. 14 N., R. 11 E., to about 500 feet in T. 16 N., R. 8 E., which is in the Bristow area. The Pitkin-Morrow could not be correlated with any of the formations above the Mississippi lime this far west with any degree of certainty. The Mississippi lime is practically the same in character and thickness as in the Okmulgee district, the thickness of the Mississippi lime in general being thinner on the tops of domes. The Chattanooga shale and a white limestone probably equivalent to the so-called White lime of the Okmulgee district are also present, the former being about 80 feet and the latter at least 55 feet in thickness. The latter horizon if it is equivalent to the White lime contains more sandy material. Some of the samples at the top and at intervals below consist of highly calcareous sands. Samples from the base of this formation consist of typical limestone with some sand which in some wells is the deep producing horizon. No wells in the immediate area have been drilled to the Ordovician siliceous limestone. Other wells in the general vicinity have been drilled to the Tyner formation.

Cushing Area

The Cushing area is probably one of the most interesting areas in northeastern Oklahoma for a study of the sub-surface conditions in the pre-Pennsylvanian formations. The pre-Pennsylvanian was correlated by means of cross sections from the Okmulgee district and the Glenn pool. The interval between the Bartlesville sand or its approximate equivalent and the Mississippi lime from the Glenn pool to the eastern edge of the Cushing field across T. 18 N. is as follows: R. 11 E., 200

feet; R. 10 E., 300 feet; R. 9 E., 300 feet; R. 8 E., 350 feet; and R. 7 E. (east side of township), 300 feet. The Mississippi lime, Chattanooga shale, and Tyner formation can be correlated in the Cushing area. Scarcely any wells to the east or southeast have been drilled much deeper than the top of the Tyner formation ("Wilcox" sand). In the territory immediately surrounding the producing area of the Cushing field where not affected by the folding of this area, the conditions are normal in so far as the persistence of the pre-Pennsylvanian formations are concerned.

East of the Cushing field the interval between the top of the Wheeler sand (usually correlated with the "Oswego" lime) and the Mississippi lime is approximately 800 feet. Westward in the direction of the field and as the crests of the domes are approached, this interval decreases and the Mississippi lime thins. Near the crests of the prominent folds such as the Drumright and Dropright domes, such deep wells as have been drilled reveal abnormal conditions and a very interesting problem in correlation. The interval between the Wheeler and the siliceous lime in some cases is probably not more than 600 feet. Near the crest of the Dropright dome a deep well has been drilled to a depth of 3,390 feet in the SE¼ sec. 17, T. 18 N., R. 7 E. The writers' correlation of the lower part of the log of this well is as follows: Sand 2,430 to 2,550 feet, (probably Bartlesville and Tucker sand as known by the drillers); Ordovician siliceous limestone 2,550 to 3,390 feet. The equivalent of the sand from 2,430 feet to 2,550 feet is logged by the drillers in other wells similarly located with respect to domed areas in this field as consisting of gray and green sandstones and green shale beds. The lower part of the above sand may or may not be equivalent to the Tyner formation. This question will be discussed in another place. It seems that the Mississippi lime and Chattanooga shale are entirely absent near the crest of this dome.

On the Drumright dome in the SW¼ sec. 33, T. 18 N., R. 7 E., no wells have been drilled below the Tyner formation. The same characters for the Bartlesville and Tucker sands, gray and green sandstone and green shale, are here present. Sev-

eral miles to the east which is considerably lower on the dome the interval between the Wheeler sand and the Mississippi lime is about 700 feet. No deep wells have been drilled immediately west of the dome. It is reported that granite has been encountered, at a depth of 3,670 feet, in a well drilled near the crest of the Shamrock dome in sec. 22, T. 17 N., R. 7 E.

If the conditions found in other areas are considered, the history of deposition and local folding in the Cushing field is apparently as follows. If folding occurred at all it was local and of minor importance during the deposition of the Ordovician siliceous limestone, Tyner formation, Chattanooga shale, and the Boone, Chester and Morrow formations. Since in other areas there has been a greater amount of folding in the Mississippian and older formations than in the Pennsylvanian, and since the Mississippian formations have been eroded more on the crests of local folds than elsewhere, the time of such local folding was late Mississippian or early Pennsylvanian and preceded the deposition of the Pennsylvanian formations which overlie the Mississippian.

No definite conclusions have been reached as to the age of the green sandstone and green shale immediately above the siliceous limestone in areas near the crests of the domes in the Cushing field. The description of these as given in the logs and as revealed by the examination of such well cuttings as were available corresponds fairly well with the Tyner formation, which in other localities is immediately above the Ordovician limestone. However, it is thought that at least the upper part of this sandstone body is probably the Bartlesville sand of Pennsylvanian age and it is also possible that the greater portion of the lower part (Tucker sand) might be a product of erosion of Pennsylvanian age derived from the Tyner formation. Additional data are necessary to made a definite correlation. The domes of the Cushing field show a greater amount of folding and subsequent erosion preceeding the deposition of Pennsylvanian sediments than any others in this general region known to the writers.

Yale Area

The Yale area is located in Ts. 9 and 20 N., Rs. 5 and 6 E., about 6 miles northwest of the north end of the Cushing field.

The correlation of formations here was determined by a cross section from the Cushing field and by another from the Cushing field north to the Jennings field then southwest to this area.

The interval between the "Oswego" lime or its approximate equivalent and the Mississippi lime in T. 18 N., R. 5 E., is about 580 feet, whereas to the north in T. 19 N., R. 5 E., it is slightly less than this amount, and in secs. 12 and 13 of the latter township near the crest of the Yale anticline it is not over 540 feet. At this place the interval from the top of the Bartlesville sand to the Mississippi lime is about 240 feet. The Mississippi lime has the same characteristics as in the other areas described, being a black shaly limestone. Its thickness is somewhat less on the crest of the fold, samples from one well showing a thickness of less than 80 feet. The Chattanooga shale is also present with a thickness of 50 to 60 feet. The Tyner formation (Mounds sand series) is the deepest producing formation, with the possible exception of the Ordovician siliceous lime. The green shale associated with the Tyner shows up also in this area. Above the Tyner formation there is in most places 10 to 15 feet of white or gray crystalline limestone, which may be the so-called White lime found in the Bristow and Okmulgee districts. The unconformable relations of the Pennsylvanian and Mississippian are present here as in the Cushing field and other areas, the Mississippian and older formations being folded and eroded prior to the deposition of the Pennsylvanian.

OSAGE DISTRICT

General Description

Included in this district are many areas in Osage county, Oklahoma, where a considerable number of wells have passed through the Mississippi lime. There are many local areas where production has been encountered below the Mississippi lime in what is usually known as the second break in this formation. The horizon of production is not always the same stratigraphically, in some cases being the same or equivalent to the Mounds sand series which is placed in the Tyner formation by the writers, and in other cases in the top of the Ordovician limestone. It will be impossible in this paper to discuss in detail the various fields where oil and gas are obtained from below the

Mississippi lime, but brief remarks may be made concerning the district as a whole and certain important areas within it. It is in this district that a considerable number of well cuttings were obtained from the Mississippian and older formations.

The cross sections previously described were extended and correlations made from the Cushing area and east of the Cushing area, the Yale, Jennings, Meramec and Glenn pools practically all of them uniting at the Boston pool in sec. 1, T. 21 N., R. 7 E., in southern Osage county. From there, cross sections were extended to various parts of the district, the main one being from the Boston pool north to the Gilliland field in T. 23 N., R. 7 E., north to T. 25 N., R. 8 E., and thence west across western Osage county to the Ponca City field in T. 25 N., R. 2 E., Kay county.

The interval between the Bartlesville sand and the Mississippi lime in the Osage district, varies considerably, being about 300 feet in the southeastern part and disappearing in the western part. The interval from the "Oswego" lime to the top of the Mississippi lime also decreases from east to west, being over 550 feet in the eastern part and less than 350 feet in the northwestern part. A bed of red shale 50 to 100 feet or more above the top of the Mississippi lime is found in many wells drilled to this horizon in western Osage county. It is not certain that it is the same horizon in all places, as it possibly represents an erosional unconformity in the basal part of the Pennsylvanian of this region. As a rule there is some difference in the character of the dark gray shale immediately above it as compared to the black shale usually found below it. In some areas several beds of red shale are found at this horizon.

The Mississippi lime in the southern part of the district is the typical black limestone of this horizon and it ranges in thickness from 100 feet in the northeast to 300 feet in the south. Northward a gray chert bed is present above it, the thickness gradually increasing to as much as 150 feet in the extreme northeastern part. It is absent in the south. There is a distinct unconformity which is structural as well as erosional in some areas above the Mississippi lime. Where local folding has taken place, the gray chert above the black limestone has been

entirely removed, so that the Pennsylvanian is in contact with the black limestone, whereas in wells drilled adjacent to the areas of folding, the gray chert is encountered at the top of the Mississippi lime. In the southern part of the area the black Mississippi lime rests unconformably on the Chattanooga shale or the Tyner formation, but in the northern and northeastern parts a gray limestone and chert member is present in the interval between the base of the black member and the Chattanooga shale. This lower limestone and chert member which is not present in the southern part gradually attains a thickness of at least 100 feet in the northeastern part. It seems possible that there are four unconformities associated with the Mississippi lime here, one above and another below the upper gray chert member, another between the base of the black limestone and the lower gray chert and limestone members and still another at the base of the last member. A discussion of the age of these members is given in another part of this paper.

The Chattanooga shale is generally present in the Osage but locally is wanting, having been eroded prior to the deposition of the Mississippi lime. The thickness ranges up to 75 feet.

The Tyner formation also extends through practically all of this district with the possible exception of the northeastern part where it is mostly local, and in other areas where it is locally absent, the Chattanooga shale in these places resting directly on the Ordovician siliceous limestone. The thickness ranges up to 100 feet. The Tyner formation is a producing horizon in a number of places in Osage county. There seems to be an unconformity between the Tyner formation and the siliceous limestone. The Ordovician siliceous limestone has been penetrated to a depth of over 700 feet in several wells and is principally a siliceous and chert limestone usually alternating with oölite, chert, and sandy limestone. The percentage of limestone varies from almost 0 to 75 per cent, and silica vice-versa. The top of the formation makes an exceptionally good reservoir for the accumulation of oil and gas in some localities as it is probably brecciated and rather porous. It is known to be a producing horizon in the Boston pool and

the Gilliland field, and possibly in several other localities. In some areas the presence of large quantities of salt and hydrogen sulphide waters is common. The same condition exists in most wells drilled to this horizon in northeastern Oklahoma and Kansas.

Between Osage county and the outcrop of the Mississippian and older formations in northeastern Oklahoma only a relatively small number of wells have been drilled below the Mississippi lime. The Mississippi lime and older formations can be recognized in practically all of these wells. The Chattanooga shale is present and described as a black shale. The Tyner formation is usually present, but more or less local in occurrence. The Ordovician siliceous limestone can be recognized fairly well in the well logs and with it is associated the hydrogen sulphide water mentioned above. The so-called "radium water" at Claremore is from this horizon. At the Ordovician siliceous limestone outcrops near Spavinaw in Mayes county there are numerous hydrogen sulphide springs. The thickness of the siliceous limestone varies somewhat, being 540 feet in sec. 25, T. 25 N., R. 12 E.; 700 feet in sec. 22, T. 29 N., R. 13 E.; at least 700 feet in many parts of Osage county where no wells have passed through it; and over 1,010 feet in sec. 18, T. 28 N., R. 3 E., Kay county. Wherever drilled through, granite has been found immediately below it, except in a few cases where quartzite of probable pre-Cambrian age, occurs beneath it and just above granite.

Boston Pool Area

The Boston pool is located in sec. 1, T. 21 N., R. 7 E. Previous to the past year this pool was famous for the prolific production in the Bartlesville sand. During 1920 a new deeper producing formation was discovered. The Boston pool is located on a pronounced dome. From the Yale area to the Boston pool the interval from the top of the "Oswego" lime to the top of the Mississippi lime decreases from 540 to 460 feet. The interval from the top of the Bartlesville sand to the top of the Mississippi lime decreases from 280 to 150 feet. The Mississippi lime is a typical black limestone as found to the south and is in most cases encountered at a depth of about 2,375 feet on the

crest of the dome. Its thickness ranges from 80 to over 200 feet being not over 80 feet near the crest of the dome. The Chattanooga and Tyner formations are also present, the former about 40 feet thick and the latter about 100 feet. The uppermost part of the Tyner formation is a bed of green shale and below this there are gray and green sandstones. Below the Tyner formation is the Ordovician siliceous limestone. Samples of it are very characteristic of this formation. The upper part is the main producing horizon below the Mississippi lime in which several prolific oil wells have been completed at an average depth of 2,560 feet.

Gilliland Area

The Gilliland area is located principally in secs. 23, 26, and 36, T. 23 N., R. 7 E. The pre-Pennsylvanian stratigraphy is similar to that of the Boston pool. The average thickness of the Mississippi lime on crest of the folding is 150 feet, the principal part of it consisting of the black limestone, though in a few wells several feet of gray chert are present at the top. Thre is probably an unconformity between these two parts of the Mississippian. The Chattanooga shale is almost entirely absent, and if present is probably not more than a few feet in thickness. Almost immediately below the Mississippi lime is a bed of green shale, which is succeeded by gray, green and pink sandstones, which are correlated with the Tyner formation and have a total thickness of 60 feet or more. Production is encountered in this formation and in the top of the Ordovician siliceous limestone. The average depth to the top of the Ordovician limestone is 2,800 feet.

KAY COUNTY DISTRICT

General Description

The Kay county district includes the Ponca City, Blackwell and Newkirk fields in which some oil and gas production are obtained from the Mississippian and older formations.

The main cross section running through Osage county was continued to the Ponca City field, and from there extended north to the Newkirk field, and thence north through Cowley county, Kansas to the Augusta and ElDorado fields in Kansas.

A short cross section was also made from the Ponca City field to the Blackwell field, and another from the Ponca City field to the Billings field in Noble county Oklahoma. Correlations were determined from these cross sections and a detailed study of well cuttings.

Ponca City Field

The Ponca City field is located in T. 25 N., R. 2 E. The interval between the "Oswego" lime or its approximate equivalent and the Mississippi lime ranges from 300 to 375 feet. A red shale horizon is usually 10 to 50 feet above the Mississippi lime the depth to the top of the Mississippi lime varying from 3,650 to 3,910 feet. The Mississippi lime contains two members, the upper consisting principally of gray chert and the lower of black shaly and cherty limestone. The upper member varies in thickness from almost 0 on the highest parts of the anticline to over 75 feet at lower elevations on it. The black limestone member varies in thickness from 225 to 350 feet and makes up the remainder of the Mississippi lime. The Chattanooga shale varies from 5 to 30 feet. At the base of the Chattanooga shale there is a thin bed of white sandstone, locally absent, below which is a bed of brown to gray chert ranging in thickness from 8 to 15 feet. This chert grades downward into dark hard sandstone. The base of the chert and the dark hard sandstone which is the deepest producing sand in the Ponca City field are here named the Marland sand. Below the Marland sand are the typical sandstones and green shales of the Tyner formation, which has a known thickness of 200 feet. The Ordovician siliceous limestone is found as in other areas below the Tyner formation. One well has penetrated the siliceous lime to a depth of 165 feet.

It is rather difficult to place the horizon of the Marland sand in the stratigraphic section, as it seems to be of local occurrence. It is possibly referable either to the base of the Chattanooga shale or the upper part of the Tyner formation.

The anticline on which the Ponca City field is located affords an excellent example of increasing dips of the formations with depth. Two deep wells about 1,700 feet apart, were drilled one on the crest of the anticline and the other

down the east dip. The dip between these on the 1,500 foot sand is about 100 feet, the deeper sands showing a greater dip about in proportion to depth. The top of the Mississippi lime shows an east dip of 330 feet, while on the Chattanooga shale it amounts to 525 feet.

Newkirk Area

The Newkirk area includes Ts. 27, 28 and 29 N., R. 3 E., in which the most important fields are the Newkirk, Northeast Newkirk and School Land. A number of deep wells have been drilled in this area and in several localities production has been found in the Mississippi lime and older formations. The description and characteristics of these with some exceptions are essentially the same as in the Ponca City field. The Chattanooga shale and Marland sand are locally absent in the area west of the Newkirk anticline. The Tyner formation has been found in all wells drilled to this horizon. The top of the Ordovician siliceous limestone is the producing horizon in sec. 16, T. 29 N., R. 3 E. In one well drilled in sec. 18, T. 28 N., R. 3 E., the siliceous limestone was found from 3,780 to 4,790 feet a thickness of 1,010 feet, below which was encountered 30 feet of dark red quartzite with some fragments of weathered feldspar and biotite. The quartzite probably overlies granite and possibly represents sediments of pre-Cambrian age. The relation of folding to the thickness of the Mississippi lime, as described in connection with the Ponca City anticline is the same on the Newkirk anticline.

Blackwell Field

The Blackwell field is located in Ts. 27, 28 and 29 N., Rs., 1 E. and W. In going northwest from the Ponca City field to the Blackwell field the interval from the "Oswego" lime to the Mississippi lime, increases from 300 to 450 feet about midway between these fields and from there decrease to 0 in the northern part of the Blackwell field near the crest of the folding, where the top of the Mississippi lime occurs at approximately the stratigraphical position of the "Oswego" which apparently was not deposited in this particular area. Near the crest of the folding only the basal part of the black limestone member of the Mississippi lime is present, the upper part having been

eroded off after the Mississipian and older formations were folded. The Chattanooga shale and Marland sand are apparently present, the latter being one of the deep producing horizons at an average depth of 3,350 feet. The green shale and gray sandstone of the Tyner formation are also present and in about the same thickness as in the Ponca City field. The Ordovician siliceous limestone is encountered near the crest of the folding at a depth of about 3,500 feet. One well has demonstrated a known thickness for it of 865 feet, the base not being reached. Previous to the deposition of the Pennsylvanian sediments in this area, considerably more folding seems to have taken place than in the other areas of this district. There is a possibility that the Blackwell field is a continuation of or in alignment with the so-called granite ridge of Kansas.

AUGUSTA-EL DORADO DISTRICT

General Description

This district includes the area of or adjacent to the well known Augusta and Eldorado fields in Butler county, Kansas. The cross section was extended from Kay county, Oklahoma northward through Cowley county, Kansas, to these fields. There has been a sufficient number of deep wells drilled along the line of this cross section, together with well cuttings from some to make fairly accurate determination of the correlations of the pre-Pennsylvanian to the Augusta-Eldorado district. In a well drilled in sec. 26, T. 34 S., R. 6 E., Cowley county, a gray and cherty bed of limestone was encountered between the base of the Black limestone and the Chattanooga shale which is probably equivalent to the lower gray limestone and chert member of the Mississippi lime in northern Osage county, Oklahoma. The upper gray chert, the black limestone and the lower gray limestone and chert members of the Mississippian can be followed northward for some distance from the Kansas-Oklahoma line, but they cannot be distinguished as separate members in the well logs as far as the Augusta field. The interval between the approximate equivalent of the "Oswego" lime and the Mississippi lime gradually decreases from 300 feet in northeastern Kay county, to about 200 feet in

T. 32 S., R. 4 E., Kansas, and from there northward increases to about 280 feet, immediately south of the south end of the Augusta anticline in T. 29 S., R. 4 E. On the crest of the Augusta fold in sec. 17, T. 28 S., R. 4 E., the interval from the top of the "Oswego" lime to the top of the Ordovician siliceous limestone is not over 260 feet. The Mississippi lime is fairly constant in thickness, except in areas affected by folding. From the Kansas-Oklahoma line northward it gradually decreases from 300 near Arkansas City to 200 feet in sec. 18, T. 30 S., R. 4 E., and from there northward the decrease is greater in proportion as the south end of the Augusta anticline is approached at Douglass. In tracing the Mississippian up the dip of this fold it gradually thins and disappears from the section. From Montgomery county, and eastward, and in northern Greenwood and eastern Chase counties, Kansas, the Mississippi lime consists almost entirely of gray chert and limestone, the black limestone member either being absent or equivalent to a part of the gray chert and limestone of these areas. It is not known definitely that the same changes has taken place between the Kay county, and the Augusta and Eldorado fields. The Chattanooga shale, Tyner formation and the Ordovician siliceous limestone can all be identified in the area of this cross section.

A cross section was made from the Eldorado field southeastward through Elk and Montgomery counties, Kansas, to the northeastern part of Oklahoma adjacent to the outcrops of the Mississippian and older formations.

Augusta Field

The Augusta field is located several miles south and northwest of Augusta, Butler county, Kansas. In this field at least a part of the pre-Pennsylvanian formations can be recognized. On account of certain structural features some of the older formations are thought to be absent. The Mississippi lime is not present near the crest of the folding in this area as explained above. What may possibly be the Tyner formation is, however, present, as shown on the cross section, and is a producing horizon in this field. Samples of it show gray and brown sandstone and green shale. Some of the wells drilled to the

east, north and south of the folded area, record the same kind of material below the Mississippi lime. It is possibly not present or at least very thin throughout the field, having been eroded off of the highest domes. Immediately below the series of green shale and sandstone is the Ordovician siliceous limestone, samples of which are very characteristic. Some of the production in this field is found in the top of this horizon and the sands associated with the green shale. In Varner No. 31, sec. 17, T. 28 S., R. 4 E., the siliceous limestone was found to be about 350 feet thick, granite being encountered below it at an approximate depth of 2,865 feet. In going north from the south Augusta anticline to the south end of the main Eldorado fold, a deep syncline is crossed in which formations stratigraphically corresponding to the Mississippi lime and Chattanooga shale return to the section, the former being described as sandy lime, chert or lime in the logs with about 50 feet of black shale below it, and below the latter, green sand and shale for a known thickness of 175 feet.

Eldorado Field

The Eldorado field is located north of the Augusta field and just west of the city of Eldorado. The correlations described in the preceding paragraph were continued to the main part of the Eldorado field from the syncline to the south. The Mississippi lime and Chattanooga shale disappear from the section before the crest of the fold is reached. However, green shales and sandstones, which are thought to be the equivalent of the Tyner formations as described in the other area are present, except possibly in the areas on or adjacent to the highest parts of the folding and are approximately the same in extent and character as in the Augusta field, as well as being one of the important horizons of production. The upper part of the Ordovician siliceous limestone, as in the Augusta field, is also an important source of oil. On some of the highest points of the folding, the siliceous limestone is almost in contact with Pennsylvanian beds, possibly being separated from them by a thin veneer of sandy material. One well, Shumway No. 27, sec. 11, T. 26 S., R 4. E., passed through the siliceous limestone which had a thickness of about 350 feet and encountered

granite immediately below it. Several wells on the north slope of the main fold have penetrated a known thickness of about 900 feet of the limestone without encountering granite. In the Shumway well mentioned the producing horizon is a "honey-comb" chert. Other wells similarly situated with respect to the folding have encountered the same kind of chert which graded downward into the typical siliceous limestone. It is not uncommon to find chert at various horizons in this formation. In going northwest from a dome in sec. 8, T. 25 S., R. 5 E., the Mississippi lime and Chattanooga shale or what is thought to be their equivalents reappear in the section. The unconformable relations of the Pennsylvanian and other formations are discussed in connection with the granite ridge in another part of this paper.

ELBING-PEABODY-FLORENCE DISTRICT

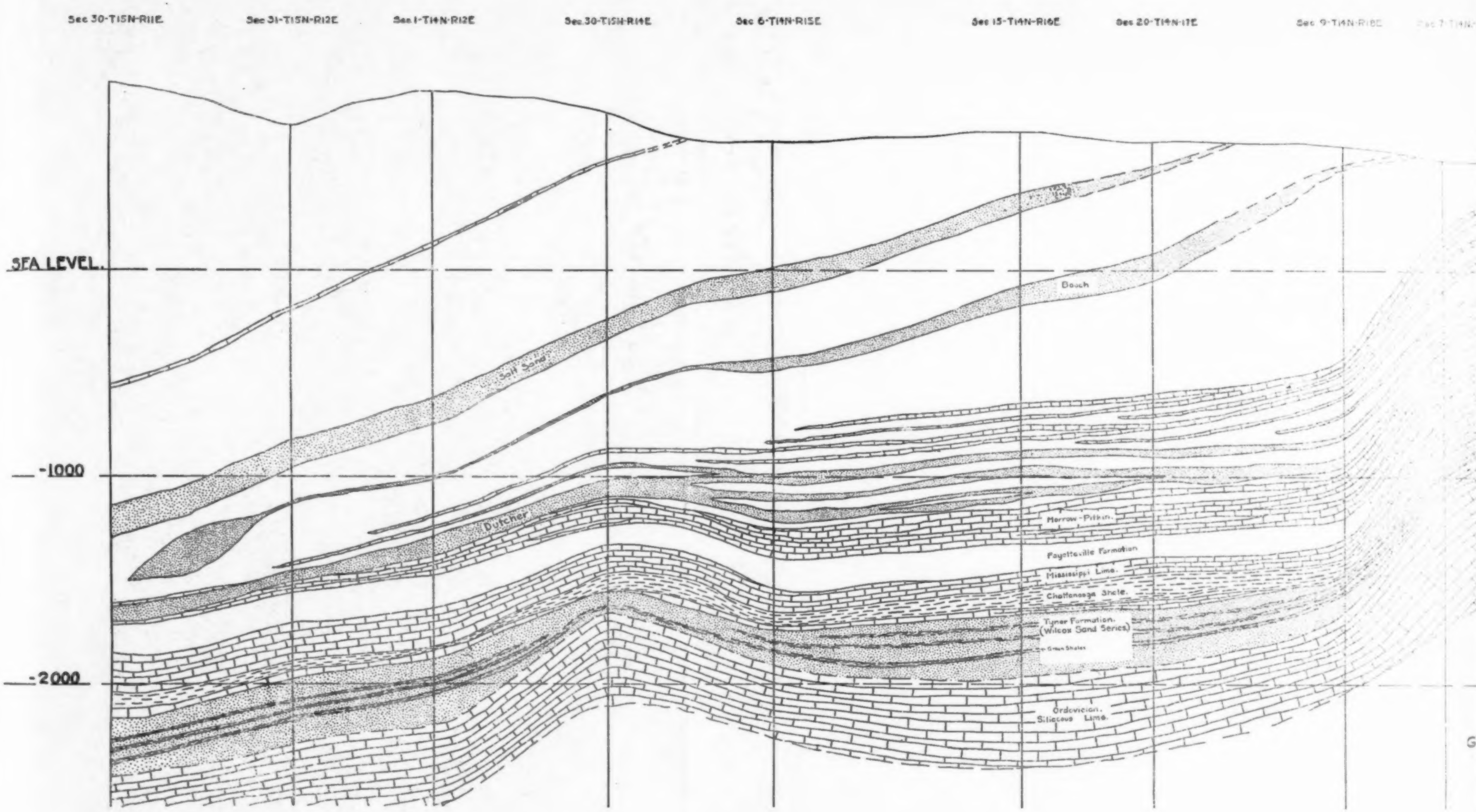
General Description

This district consists of the producing and adjacent areas in the Elbing field, T. 23 S., R. 4 E., the Covert-Sellars field, T. 21 S., R. 4 E., and the Urschell field, T. 21 S., Rs. 4 and 5 E.

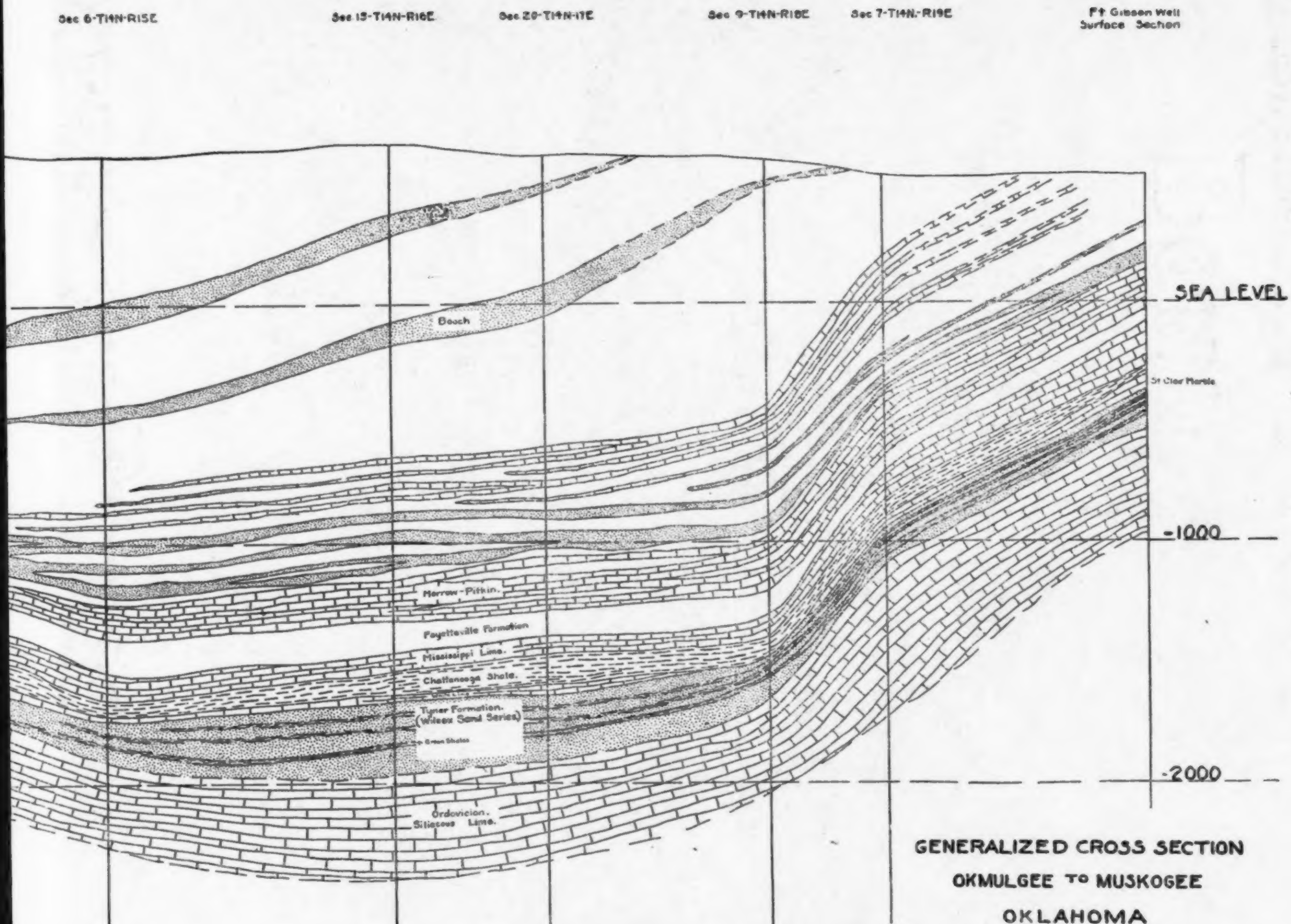
The main cross section was extended from sec .8, T. 25 S., R. 5 E., at the north end of the Eldorado field, in a general northwest direction to the Elbing field, then north to the other fields in this district. The correlations were determined from the logs of wells which have been drilled between the Eldorado and Elbing fields, but only a few of them have been drilled deep enough to furnish data for these correlations. The Missisipi lime and Chattanooga shale or their probable equivalents appear in the section on leaving the Eldorado field and are present until the Elbing pool is reached, where the same change relative to them takes place as in the Augusta and Eldorado fields. The same conditions exist between the Elbing and Peabody fields.

Elbing Field

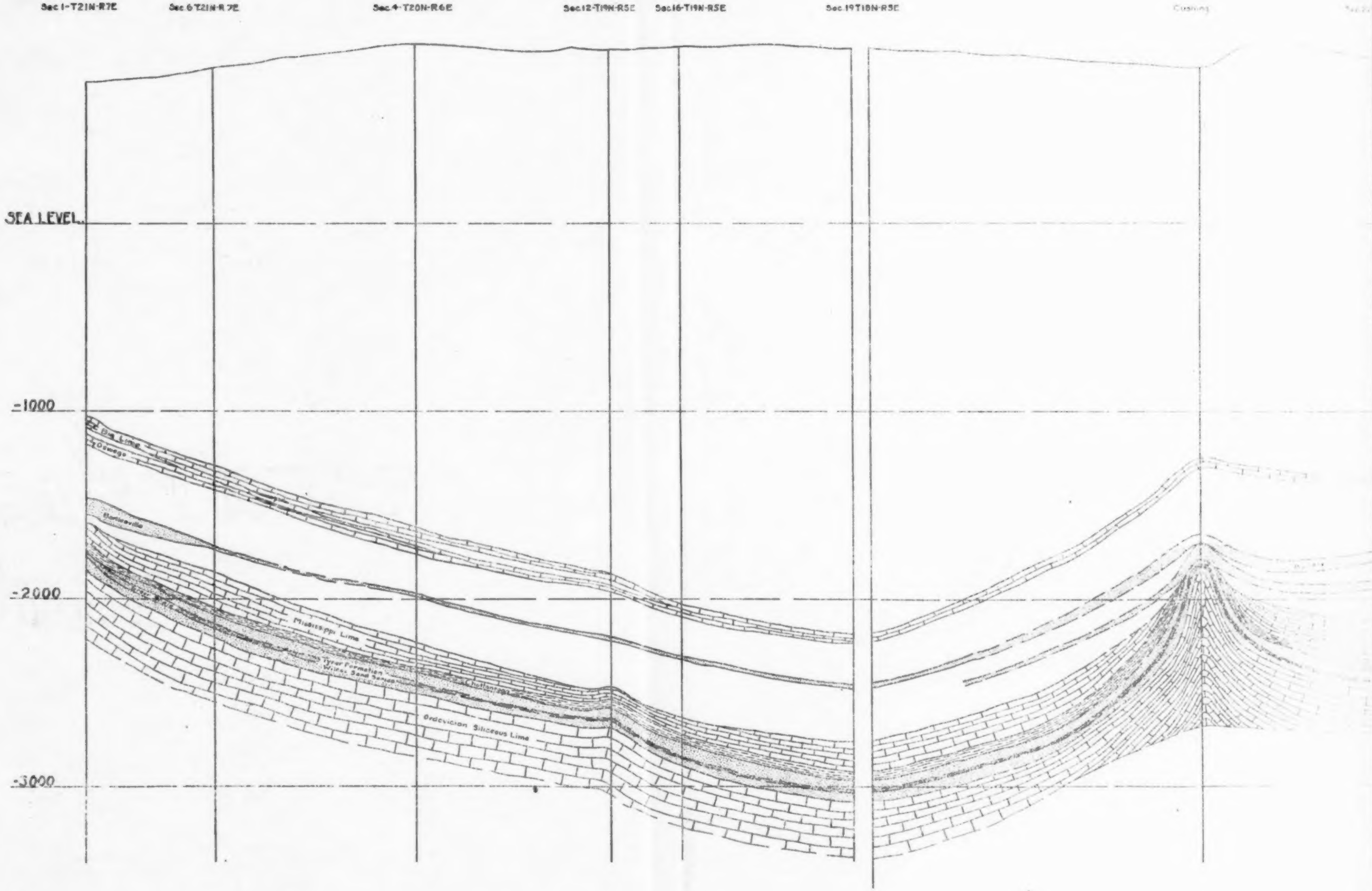
In the Elbing field there is some question as to the stratigraphic position of the main oil producing horizon. Very few wells have been drilled below the producing horizons. The log of one well record shows sand from the top of the producing horizon, which is encountered at an average depth of 2,450



Sec 30-T15N-R11E
Sec 31-T15N-R12E
Sec 1-T14N-R12E
Sec 30-T15N-R14E
Sec 6-T14N-R15E
Sec 15-T14N-R16E
Sec 20-T14N-17E
Sec 9-T14N-R18E
SEA LEVEL.
-1000
-2000
Salt Sand
Bouch
Dutcher
Morrow-Pitkin.
Fayetteville Formation
Mississippi Lime.
Chattanooga Shale.
Tyner Formation.
(Wilcox Sand Series)
Green Shales
Ordovician.
Siliceous Lime.

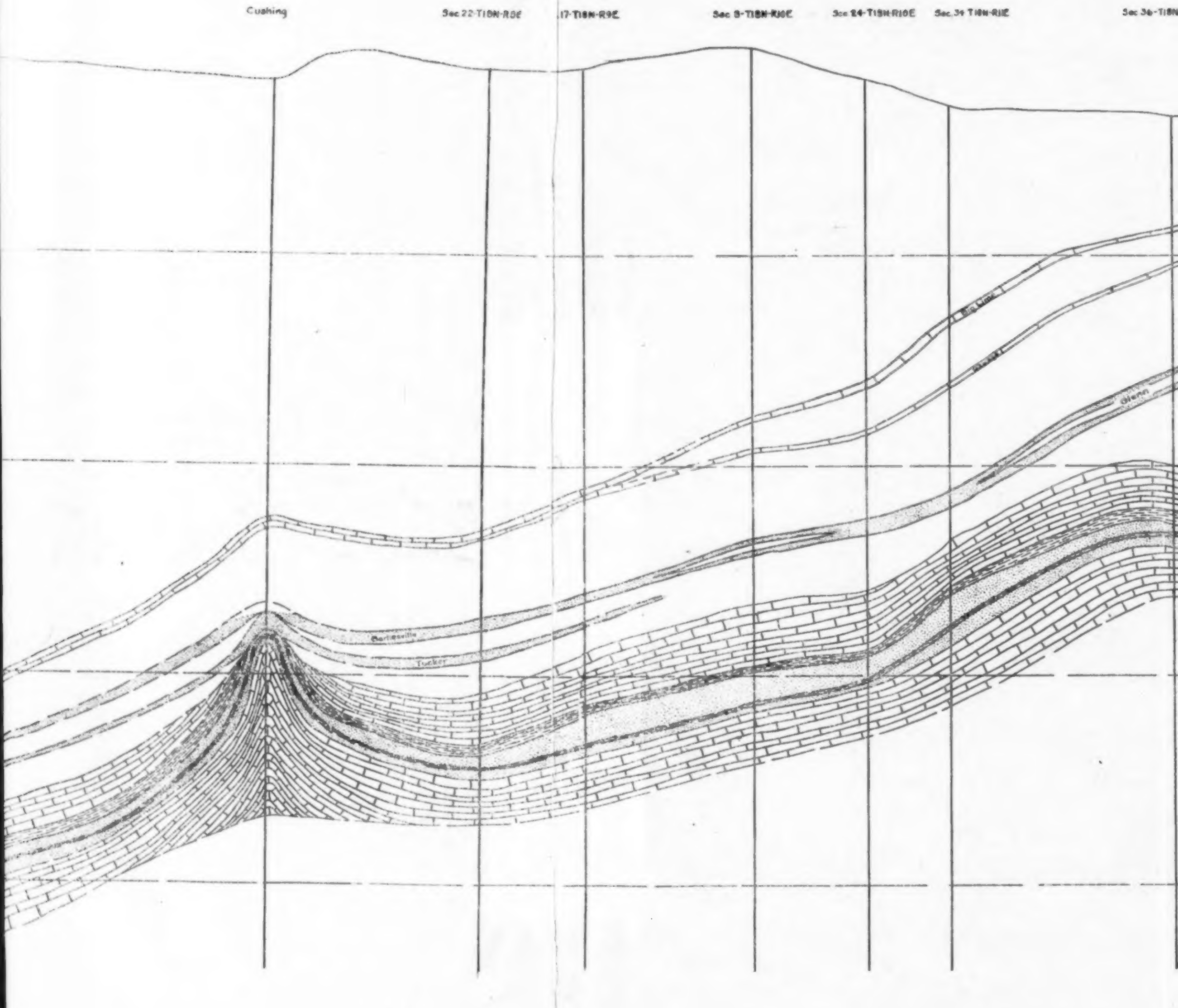


GENERALIZED CROSS SECTION
OKMULGEE TO MUSKOGEE
OKLAHOMA

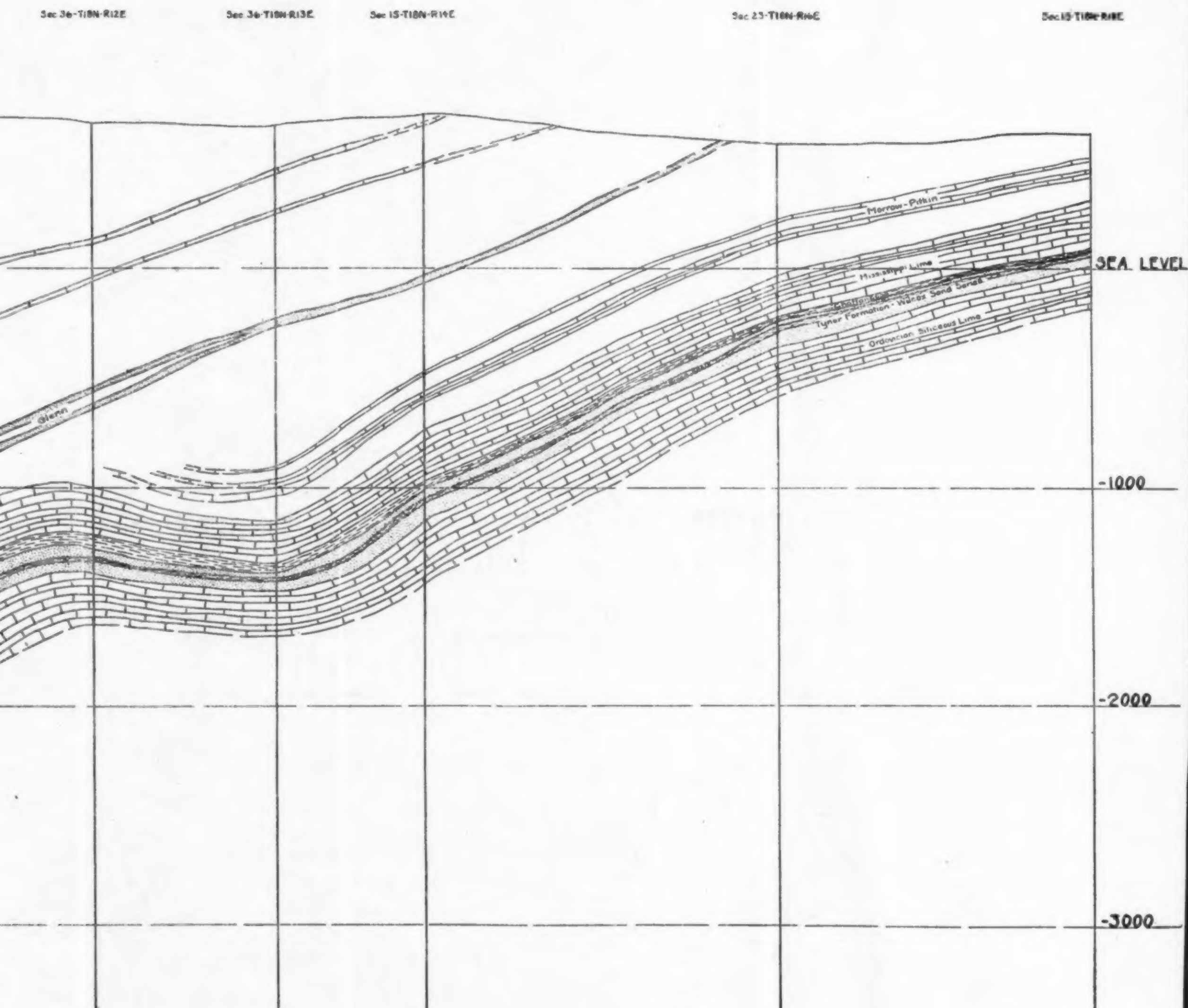


Sec 1-T21N-R7E
Sec 6 T21N-R 7E
Sec 4-T20N-R6E
Sec 12-T19N-R5E
Sec 16-T19N-R5E
Sec 19 T18N-R5E
Cushing
SEA LEVEL
-1000
-2000
-3000
Big Lime
Oswego
Bartlesville
Mississippi Lime
Tyner Formation
Wilcox Sand Series
Chattanooga
Ordovician Siliceous Lime

GENERALIZED C
BOSTON POOL-TI
OKLAHO



RALIZED CROSS SECTION
ON POOL-T18NR5E-WAGONER
OKLAHOMA



feet to a total depth of almost 450 feet below. The uppermost part of this so-called sand is possibly equivalent to the sands of the Tyner formation but it is also thought that the lower part may be equivalent to the Ordovician siliceous limestone, as it is not uncommonly logged as sand by the drillers.

Peabody Field

The stratigraphic position of the producing sand which usually is encountered at a depth of 2,525 feet in the Peabody field is thought to be the same as in the Elbing field. Several deep wells have been drilled in this area, so that more definite correlations can be made. The Tyner formation, the uppermost part of which is the producing horizon, is at least 200 feet thick and includes green, blue and red shales and gray sandstones. The Ordovician siliceous limestone is also present below the Tyner formation. No great stratigraphic change is noted from the Peabody to the Covert-Sellars field. In the latter the producing horizon, which is encountered at an average depth of 2,350 feet, is commonly a chert bed and is succeeded below by the typical sands and occasional green shale beds of the Tyner formation, which has an average thickness of several hundred feet. The Ordovician siliceous limestone is encountered below the latter as in the other areas.

Urschell Field

The producing horizon in the Urschell field is similar and is the same in stratigraphic position as in the Covert-Sellars field. Other conditions are also similar. In going northwest from this field which is down the dip from the folded area, a cherty limestone formation which is absent in the Urschell field comes into the section. This formation occupies the stratigraphic position of the Mississippi lime, but the writers do not attempt to place it definitely in the section. It has a maximum thickness of about 100 feet and the base is about 170 feet above the chert in the top of the Tyner formation. One well in sec. 25, T. 20 S., R. 5 E., northeast of the Urschell field, penetrated a thickness of 435 feet of Ordovician siliceous limestone, below which granite was encountered.

FOLDING ASSOCIATED WITH THE GRANITE RIDGE

The relation of pre-Pennsylvanian folding to Pennsylvanian

sedimentation in the Augusta, Eldorado, Elbing, Florence and other fields of this general region in Kansas, associated with the Granite ridge is a very interesting structural problem. If the writers' interpretations are correct a number of structural movements took place from Ordovician at least to Permian time. It is reasonable to assume that the granite of this region is pre-Cambrian in age and a part of the old pre-Cambrian basement, and that the Granite ridge was an elevated range of hills or mountains at that time. During the Cambrian and Ordovician, the ridge or at least the greater part, was competely submerged. After the deposition of the Ordovician siliceous limestone there was probably some folding in which the siliceous limestone was elevated above the sea and eroded to some extent, then re-submerged during which time the sandstones and green shales of the Tyner formation, if such is the correct correlation, were deposited. As far as available data can be interpreted no folding of consequence occurred until after Mississippian time when the ridge received another uplift either at the close of the Mississippian or in the early Pennsylvanian. Following the latter uplift above the sea all of the Mississippian, and Devonian sediments were removed by erosion from that part of the ridge in the Augusta, Eldorado, Elbing, Peabody and Florence fields, before the Pennsylvanian sea again completely submerged it. Farther north on the ridge a greater period of erosion took place in which all formations from the Mississippian to the pre-Cambrian granite were removed before submergence by the Pennsylvanian sea. Other slight movements took place during Pennsylvanian time. There are two probable explanations for folding during these periods of time, namely vertical uplifting or periodical settling of the sedimentary formations around this old land mass.

EASTERN KANSAS

A considerable number of deep wells have been drilled in widely separated localities in eastern Kansas. In most of these the Mississippi lime has the usual thickness of about 300 feet. Locally a black shale probably equivalent to the Chattanooga shale is found below the Mississippi lime. The equivalent of the Tyner formation cannot be recognized as such in the well

records, although some wells report sandstone below the Chattanooga shale which may be equivalent to the Tyner formation. In general, the Ordovician siliceous limestone is encountered next below the Mississisppi lime or the Chattanooga shale. Hydrogen sulphide water is usually encountered in the uppermost part of the siliceous limestone.

During the past year oil production has been discovered below the Mississippi lime in Elk and Chautauqua counties near the towns of Grenola, Howard, and Moline. This production is probably in the Tyner formation or the upper part of the Ordovician siliceous limestone.

SUMMARY

During the past four or five years important oil fields have been discovered in horizons of the Mississippian and older formations in Kansas and Oklahoma. From a study of well cuttings and a series of cross sections constructed from well logs, an attempt is here made definitely to correlate some of these horizons and to suggest possible correlations of others. To summarize the writers' conclusions and at the same to discuss briefly the paleogeography of the pre-Pennsylvanian it is thought best to begin with the older formations.

The granite underlying the sedimentary rocks of this region is most likely pre-Cambrian in age. The only surface exposure is at Spavinaw, in Mayes county, Oklahoma. At this place the granite is an old peak of the pre-Cambrian basement and was not completely submerged until Ordovician time. The Granite ridge of Kansas is a similar example of pre-Cambrian and early Ordovician topography. In general the granite floor is fairly flat.

Immediately above the granite in all areas except part of the Granite ridge of Kansas is a thick formation of sandy, cherty, and siliceous limestone, which is considered here to be of Cambro-Ordovician age. Its probable equivalent in the Ozark section is the Yellville limestone of the Fayetteville quadrangle where it is described by G. I. Adams and E. O. Ulrich[9] as a light to dark gray magnesian limestone and dolomite, locally siliceous and cherty. The Arbuckle limestone

[9]U. S. Geol. Survey, Geologic folio No. 119.

of the Arbuckle mountains or at least a part of it is thought to be the equivalent of the siliceous limestone at Spavinaw. This formation which is here called Ordovician siliceous limestone ranges in thickness from 200 feet or less to over 1,000 feet. Very few wells have been drilled through it, and none of them as far as known have passed through it in the Okmulgee district, Oklahoma, so that no definite estimates can be made of its thickness there. Normally it has a thickness ranging from 600 to 1,000 feet in Kansas and northern Oklahoma. Some of the production in T. 23 N., R. 7 E., the Boston pool and several other localities in Osage county, sec. 16, T. 29 N., R. 3 E., Kay county, in Oklahoma and in the Augusta and Eldorado fields, and possibly the Elk county fields in Kansas, is obtained from the uppermost part of this formation. One characteristic feature of the formation is that it has an abundance of salt and hydrogen sulphide waters, both at the surface and underground in Kansas and northern Oklahoma. It is very common for the drillers to log this formation as sand or sandy limestone.

The Burgen sandstone is stratigraphically above the Ordovician siliceous limestone in the Tahlequah quadrangle and seems to be of only local occurrence so that no attempt was made in the sub-surface work to differentiate it from the overlying Tyner formation, if indeed, it is present. After the deposition of the Ordovician siliceous limestone and preceding the deposition of the Tyner formation, some very slight uplift seems to have taken place in the Spavinaw area of Oklahoma and the Granite ridge in Kansas.

The Tyner formation, which is correlated with the Trenton and Lorraine of the Ordovician type section, consists of sandstones, limestones and green, red and blue shales at the outcrop of this formation in the Tahlequah quadrangle. This series of sandstones and shales can be traced westward from the west margin of the Ozark uplift by means of well log cross sections, and correlations from examinations of well cuttings. In the Okmulgee district the Mounds ("Wilcox") sand, which is a very important producing horizon, occurs in what is thought to be the Tyner formation. The Mounds sand is correlated in a general way with the sand of the so-called "second

break in the Mississippi lime" horizon of Osage county. In some localities the "second break" is approximately equivalent to the Mounds sand, in others it is the uppermost part of the Ordovician siliceous limestone and in still others it is equivalent to both the Mounds and the siliceous limestone. In the Cushing field, the Tucker sand or at least the base of it where encountered near the crests of the domes is possibly roughly equivalent to the Mounds sand as the characteristics and stratigraphic position with respect to the lower formations are the same. It is also possible that the Tucker sand as referred to above may be a Pennsylvanian erosion product from the Tyner formation (Mounds sand series). The so-called Tucker sand as encountered on the flanks of the folds is thought to be in the Pennsylvanian. The deepest producing horizons of the Elbing, Peabody, Covert-Sellars, Florence and at least a part of the Varner and Stapleton sands of the Augusta and Eldorado fields, respectively, all in Kansas, are tentatively correlated with the Tyner formation (Mounds sand series). To correlate these horizons definitely with the Tyner formation it will, however, be necessary to have additional data. Since samples of the material making up these horizons which have been examined are found to resemble very closely the Tyner formation and since the stratigraphic positions are the same, the writers suggest this correlation. On the other hand these producing horizons in Kansas may have been deposited as products from the erosion of the Tyner, and older formation during the Pennsylvanian. The writers are inclined to believe that the correlation with the Tyner formation is most probable. In the typical Mounds or "Wilcox" sand developed area in the Okmulgee district a bed of white to gray crystalline limestone, which is also sandy in some localities, occurs immediately above the "Wilcox" sand. Fragments of this limestone were sent to Mr. E. O. Ulrich, of the U. S. Geological Survey for determination of the fossil contents and he writes:

The fossils in question are very imperfect, and I have not the time to make a thorough investigation of either the specimens or the probabilities as regards the stratigraphy. The region in which your wells occur lies in the western province of which the sequence of neither the formations nor the fossil faunas can be definitely compared and correlated with

those of our standardized sections in and to the east of the Mississippi valley. * * * The second lot of fossils, though extremely fragmentary, recall to me only some Richmond (early Silurian) formation. Limestone of similar sub-crystalline types range widely to the southwest, west and north. Everywhere they contain more or less easily determinable remains of the highly characteristic lower Richmond fauna. In your well cuttings I note a piece of shell that indicates *Rhynchotrema capax*, an imperfect valve of a *Dalmanella* that agrees very well so far as it goes with *D. tersa*, and fragments of a *Bumastus* like *B. vigilans*. Their cumulative evidence is fairly conclusive of the Richmond age of the bed in question.

In the Arbuckle mountain section the upper member of the Viola limestone is of Richmond age[10] so that the "white lime" of the Okmulgee district may be tentatively correlated with the upper member of the Viola limestone. At the outcrop of the Tyner formation in the Tahlequah quadrangle the upper most beds carry a Lorraine fauna[11]. The next beds below are calcareous sandstone and cherty limestone which are correlated by Ulrich[12] with the lower Trenton or Black River. The upper beds of the Tyner may possibly be correlated roughly with the lower and middle Viola of the Arbuckle mountain section. These beds do not seem to be present or are not recognized as such in the Okmulgee district. At the outcrop of the Tyner formation no fossils have been described, in the lower part, which consists principally of sandstone and green and red shales. In the Arbuckle mountain section the only formation having a lithologic resemblance and a near stratigraphic position is the upper part of the Simpson formation, which is correlated with the upper Stones River. It is not improbable that the lower part of the Tyner is equivalent to at least a part of the upper Simpson formation. The Tyner formation as here used in the Okmulgee district is thought to represent only the lower part of this formation.

The Chattanooga shale is very widely distributed but it is locally absent. The correlation of this formation in the various districts considered in this paper are based entirely on the character, conditions of general occurrence, and stratigraphic

[10]Taff, J. A., U. S. Geol. Survey, Prof. Paper No. 31, 1904.
[11]Taff, J. A., U. S. Geol. Survey, Geologic folio No. 122, p. 2, 1905.
[12]Op. cit.

position and not from paleontologic data as no recognizable fossils have been found in well cuttings from this horizon. The Chattanooga shale is usually regarded as the approximate equivalent of the Woodford chert of the Arbuckle mountain section.

The Mississippi lime as found in several districts can be divided on the basis of lithologic characters into three separate members. The lowest member, a gray limestone and chert, is present in Kansas and northeastern Oklahoma. From a thin member in Osage county, Oklahoma, it increases in thickness to the north and east where it apparently becomes a prominent part of the Mississippi lime. A complete specimen of a brachiopod was found in well cuttings from this horizon in a well drilled sec. 26, T. 34 S., R. 6 E. Concerning its identification Mr. E. O. Ulrich writes:

> Further cleaning of this specimen establishes quite definitely that it is a species of *Chonetes* and a close ally of *C. ornatus*, *C. logani*. and *C. glenparkensis*. The nearest of all, as far as known to me, is a small shell of this section of a genus that is abundant in the Cuyahoga formation in northern Ohio, and which has been referred to *C. logani* by authors. However, your specimen is not exactly like any of the varieties known to me. On the other hand all of its close allies are confined in and to the east of Mississippi valley to beds of early Mississippian ages—Kinder hook and Burlington formations, so that for the present we are warranted in assuming a similar age for the 30 foot bed of limestone from which your specimen was procured. In my belief this 30 foot bed corresponds essentially to either the St. Joe member of the Boone or to the true representative of the Fern Glen limestone that locally underlies the St. Joe in northwestern Arkansas (as on Eagle Creek).

If the lower member of the Mississippi lime is equivalent to the Fern Glen or St. Joe member of the Boone, then the greater part of the Boone formation is absent in Osage county and to the the south of it. In several localities in the northeastern part of Osage county, the lower members consists entirely of chert. It is possible in these cases, that the lower member is equivalent to the true Boone (Burlington and Keokuk).

The black limestone member, which is stratigraphically above the lower member is the only representative of the Mississippi lime in the Okmulgee district, the other two members being absent. This member maintains its identity at least as

far north as Cowley, Chautauqua and Elk counties, Kansas, and east at least as far as Washington, Tulsa, Wagoner, and Muskogee counties in Oklahoma. From Osage county, Oklahoma to the north and east it seems to become thinner. In Nowata county, Oklahoma, and eastern Montgomery, northern Greenwood and eastern Chase counties, Kansas, the Mississippi lime consists entirely of gray limestone and chert. No data are available to show whether the black limestone member pinches out or changes in character from black limestone to gray limestone and chert. As there are unconformities above and below the limestone member it seems reasonable to assume that it is not present in the latter areas. The black limestone member is probably equivalent to the Mayes limestone of Chester age. Such a correlation is based entirely upon faunal data, several specimens of a brachiopod, *Liorhynchus carboniferum*, having been found in the well cuttings of this horizon. This fossil is typical of the Mayes formation in eastern Oklahoma. The black limestone member is at least not younger than the Mayes formation.

The upper member of the Mississippi lime consists of gray chert and limestone. This member is not present very far south and southwest of Osage county, Oklahoma, but to the north and east it seems to be present. There is an unconformity both above and below it. If the black limestone member of the Boone formation is equivalent to the Mayes formation, what is the age of the upper member? The writers are not in a position even tentatively to correlate this member. The Mississippi lime in eastern Kansas and northeastern Oklahoma is generally considered to be the equivalent of the Boone formation. At least the lower part of it can be correlated definitely with the Boone, but additional data are necessary for a definite correlation of the upper part. The Fayetteville shale and Pitkin limestone can not be correlated definitely in the well logs west and north of the Glenn pool area.

During Cambrian, Ordovician, Silurian, Devonian and Mississippian time there were no periods of extensive folding other than in the areas which have been mentioned, though there were a considerable number of periods of submergence and

withdrawal of the seas. After the close of the Mississippian and in the early Pennsylvanian, there was a period of general local folding, especially in the Ozark uplift, Arbuckle mountains, Granite ridge of Kansas, and even in the areas between them slight movement took place. In practically all of the producing areas of the northern Mid-Continent fields associated with the prominent folds at least some warping of the Mississippian and older formations had however, taken place, before the deposition of the Pennsylvanian.

SOME PALEONTOLOGICAL EVIDENCE ON THE AGE OF THE OIL-BEARING HORIZON AT BURKBURNETT, TEXAS

By L. C. Glenn

A fortunate opportunity came to the writer last summer to obtain some richly fossiliferous material from a well in the northwestern extension of the Burkburnett oil field. The material was sent to the U. S. Geological Survey and was identified by Dr. George H. Girty. It has seemed that the lists of fossils and Dr. Girty's comments on the age of the beds should be made matter of public record since, in the writer's investigations in the Burkburnett oil field, he was early impressed with the dearth of direct paleontologic evidence as to the age of the oil bearing horizon. He could learn of practically no fossils recovered from any of the more than two thousand wells which dot that field.

The Permian age of the "Red Beds," or Wichita formation, which comprise the surface rocks of the region is now generally agreed upon.[1]

On searching the geological literature of the region very little definite paleontologic evidence could be found as to the age of the oil bearing beds. The most specific data is that given by Udden and Phillips,[2] who mention securing a score of samples from the deeper parts of several wells. in the Henrietta and Electra fields. They regard the fragments as sufficient "to demonstrate, with at least a high degree of probability, the Cisco age of these beds, irrespective of any

*L. C. Glenn, Consulting Oil Geologist and Professor of Geology, Vanderbilt University, Nashville, Tenn.

[1]Gordon, C. H., The Wichita formation of northern Texas, with discussions of the fauna and flora by G. H. Girty and David White: Jour. Geology, vol. 19, pp. 110-134, 1911.

[2]Udden and Phillips, Bulletin of the University of Texas, No. 246; A Reconnaissance Report on the Geology of the Oil and Gas Fields of Wichita and Clay Counties, Texas. Austin, 1912.

inferences based on the known structure or stratigraphic succession in the series of rocks of this region." Their list includes fragments of a number of genera only two of which, however,—*Fusulina cylindrica and Rhombopora lepidodendroides*—were capable of specific identification. A few of their fragments were from a depth of 1450 feet but most of them were from about 1800 to 2000 feet or even deeper.

Gordon[3] describes the Wichita, Cisco, Canyon, and Strawn, and gives a list of fossils obtained by him from the Cisco at Graham, Texas, which were identified by Dr. G. H. Girty, and adds a list of forms obtained by Cummins from the same locality. He gives a few well logs but does not mention fossils in connection with them. He regards the Cisco as 700 to 800 feet thick in the southern part of the region, but in the Red Beds area believes no definite statement of thickness can be made, and no clear line of division can be drawn between the Cisco and the Wichita.

Munn[4] gives surface sections of the Wichita as exposed along Red river and a number of well logs, but in the latter does not add to the fossil lists made by Udden and Phillips.

Wegemann[5] discusses clearly the relation of the Wichita to the underlying rocks and quotes from Taff, C. A. White, and Udden and Phillips as to age relationships. The logs of wells near Randlett and in Texas opposite the mouth of Cache creek show that Red Beds dominate down to about a thousand feet, below which they are thin or absent. He says[6] that "the upper part of the red shales is Permian, but the lower part may belong either to the Permian or the underlying Pennsylvanian." The only fossils mentioned are plants and vertebrate remains found in the surface Red Beds.

Last summer the Hamilton Oil Association was drilling a well

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[3]Gordon, C. H., Geology and Underground Waters of the Wichita Region, North Central Texas. U. S. Geol. Surv., Water Supply Paper 317, p 20, 1913.

[4]Munn, M. J., Reconnaissance of the Grandfield District, Oklahoma, U. S. Geol. Surv., Bull. 547, 1914.

[5]Wegemann, C. H., Anticlinal Structure in parts of Cotton and Jefferson Counties, Oklahoma. U. S. Geol. Surv., Bull. 602. 1915.

[6]Ibid. p. 31.

on the flood plain of Red river in the northwest corner of the northeast quarter of section 13, T. 5 S., R., 15 W., Tillman county, Oklahoma. The well was two miles slightly south of west of the Burk Divide No. 1, which was the nearest well of which a log was obtainable. The elevation of the Burk Divide No. 1 is 1010.6 feet, and of the Hamilton Oil Association No. 1, 1023.4 feet. In the Burk Divide the last red shale was from 902 to 1080 feet in depth and the top of the oil sand was struck at 1538 feet. Surface exposures of the Wichita beds along the river bluffs contain no identifiable key beds and do not enable the westward dip to be determined with any accuracy. As the rotary in the Hamilton well neared what was thought to be the oil horizon, a core barrel was substituted, and with it some of the best cores the writer has seen in that region were secured. These cores were about four inches in diameter, and came out in pieces 12 to 20 inches in length. At two horizons they consisted of a highly fossiliferous blue calcareous shale. These two horizons were, according to the driller's log, at first thought to be at 1661 and 1666 feet in depth. Later, cause to doubt this record arose, and a steel line measurement showed the true depth to be 1581 and 1586 feet. The writer sent the larger portion of these two pieces of core to the U. S. Geological Survey and Dr. George H. Girty has reported the identification of the forms given in the following lists. Although so very near to each other it has been thought best to keep the two lists separate.

From the 1581 foot horizon he reports

Serpulopsis insita
Rhombopora lepidodendroides
Lingulidiscina sp.
Derbya crassa?
Chonetes granulifer
Productus cora
Productus pertenuis
Pustula nebraskensis
Marginifera splendens?
Spirifer cameratus
Ambocoelia planiconvexa
Deltopecten occidentalis
Lima retifera?
Myalina kansasensis
Monopteria polita?
Schizodus sp.
Fish tooth
Bairdia sp.
Bairdia sp.
Bairdia sp.
Ostracod, n. gen. n. sp.

From the 1586 foot horizon he reports

Monopteria sp.	*Euchondria neglecta?*
Pseudomonotis kansasensis?	*Pleurophorus sp.*
Myalina swallovi?	*Pleurophorus? n. sp.*
Deltopecten mccoyi?	*Phanerotrema grayvillense?*
Deltopecten occidentalis?	*Phanerotrema? sp.*
Aviculopecten coxanus?	*Aclisina sp.*
Aviculopecten sp.	*Zygopleura? sp.*
Aviculopecten sp.	*Amphissites sp.*
Acanthopecten carboniferus	*Bairdia sp.*

Dr. Girty incorporates memoranda on the ostracoda (no foraminifera having been found) furnished by Mr. P. V. Roundy, and comments as follows on the horizons represented by the two assemblages:

I regard these faunas as well up in the Pennsylvanian, as Middle Pennsylvanian or above, though not latest Pennsylvanian. Owing to the fact that species and the associations of species were long-lived in the Pennsylvanian and that faunas are liable to show regional variation more strongly than chronologic variation, I hesitate to be more specific on this head but make the suggestion tentatively that the horizon is in the Cisco formation of the Texas section and approximately the horizon of the Topeka, Barclay and Howard limestones of the Kansas section.

Of the ostracodes found at the 1581-foot horizon Mr. Roundy recognized three undescribed species or varieties of Bairdia, of which one has been found in all the Pennsylvanian formations of Texas, the two others being known only in the Canyon and Cisco, not in the Bend or Strawn. Another form seems to be a new genus and one not observed previously in Texas at all.

From the 1586-foot horizon he obtained a well-marked species of Amphissites (undescribed) which he had previously identified in the upper Marble Falls limestone and in the basal Canyon (Palo Pinto) limestone, and also a Bairdia (new species) very similar to a common form that occurs in the Cisco, Canyon, Strawn, and Marble Falls formations.

In summation, Mr. Roundy concludes that the cuttings are Pennsylvanian and probably post-Strawn in age. If the fact has any significance I might state that Mr. Roundy's opinion and my own were formed independently. With a certain latitude they seem to be in essential agreement.

The horizon from which these fossils came is about 500 feet below the base of the beds which are prevailingly red. If the Cisco is 700 to 800 feet thick in this region, and its top were to be taken at the base of the lowest heavy Red Bed, the fossils

listed above would occur at about the middle of the lower half of the Cisco. If, as seems much more probable, the upper part of the Cisco includes a portion of the lower part of the Red Beds, this fossil horizon would occupy a correspondingly lower place in the Cisco, but it is believed that the horizon is certainly referable to this group.

It is hoped that others may contribute any similar information which may come to their notice, and that we may in this way render increasingly definite our knowledge of the subsurface horizons in this region where the surface formations are so nearly hopeless for either stratigraphic or structural tracing.

The writer would add one further paleontologic point. High level river sands and gravels are found at many places along Red river. One prominent deposit occurs at 70 to 90 feet above present water level in the Grandfield region. In a gravel pit in this deposit in the west edge of Bridgeton a well preserved elephant tooth was found last summer. It belongs apparently to *Elephas columbi*, and would make the gravels at this level of middle Pleistocene age.

GRAPHIC METHOD FOR DETERMINING THE SURFACE PROJECTION OF THE AXIS AND CREST TRACES AT ANY DEPTH OF AN ASYMMETRICAL ANTICLINE

By D. M. Collingwood

In August, 1918, a paper was published by H. S. Palmer entitled "New graphic method for determining the depth and thickness of strata and the projection of dip," which was later included in the U. S. Geological Survey Professional Paper 120—"Shorter contributions to general geology 1918."

The alignment diagrams presented therein were found to be very useful as time savers in connection with structure contour mapping from geological surveys, and it was found advisable in making estimates for the location of test wells to construct an additional alignment diagram of a similar nature, shown in Figure 1.

Figure 2 shows a diagrammatic section of an anticline to define the terms used.

Knowing the dips on each flank of an anticline, it is possible to obtain from this alignment diagram the surface offset distance from the intersection of the axial plane with the surface to the surface projection of the axis trace of a bed at any depth.

The values were obtained from the simple relationship:

$$D = d \times \tan \frac{b - a}{2}$$

where D = offset distance in feet

d = depth in feet to required horizon

b = angle of greater dip in degrees

a = angle of lesser dip in degrees

The diagram was constructed for values of "d" = 10 feet.

To obtain the offset distance, lay a straight edge on the diagram between the known values of "b" and "a", the scales for which are graduated in opposite directions. The value for depth of 10 feet is then read off the middle scale where intersected by the straight edge. The product of this value and the

depth to the required horizon, stated in multiples of ten, gives the required offset distance.

A further refinement often necessary is the offset distance

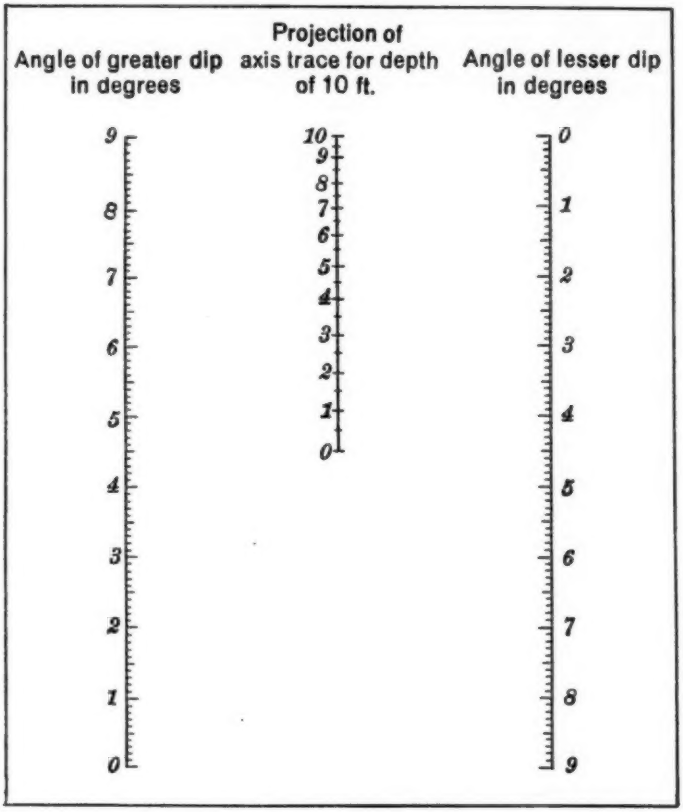

Fig. 1. Alignment diagram for determination of location of test wells on an asymmetrical anticline.

to the surface projection of the crest trace of a bed at any depth. This will be a little greater than to the axis trace at the required depth if measured from the surface intersection of the axial plane.[1]

However, in the field or on the map, it is usually as easy to locate the crest of the outcropping horizon or the projection of

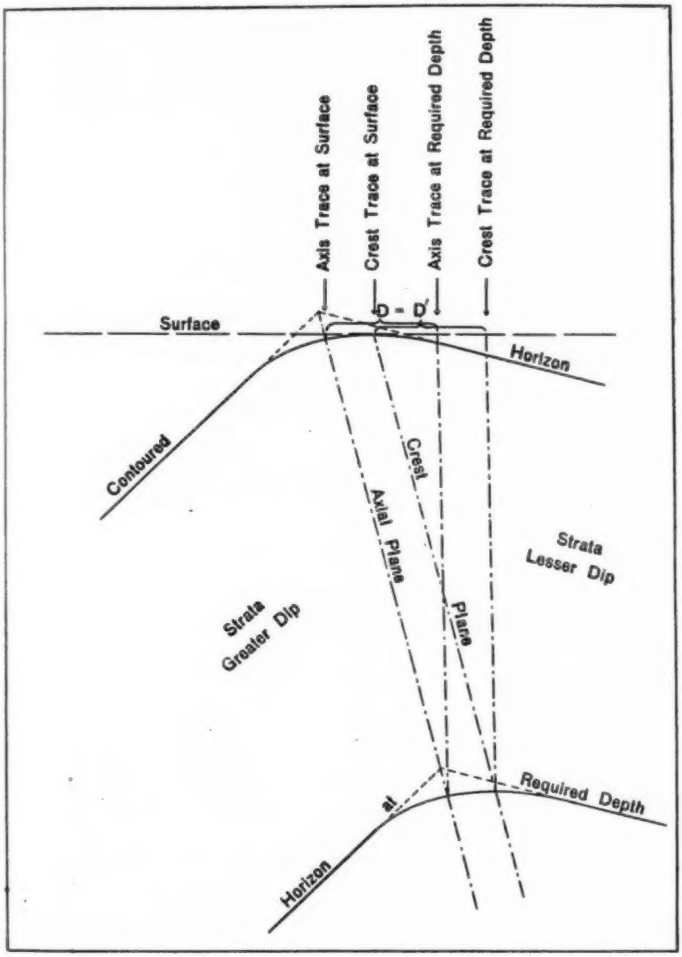

Fig. 2. Diagrammatic section of an asymmetrical anticline showing usage of terms.

the crest trace of the horizon on which the structure contours are being mapped, as it is to locate the surface intersection of the axial plane. Assuming that the folding of the beds is parallel, the axial plane and crest plane are parallel, and it is therefore necessary merely to take the value as obtained from the diagram for the trace of the axis, multiply it by the depth multiple of ten between the contoured and required horizons, and to use this as the offset distance from the crest trace of the surface or contoured horizon to the crest trace of the horizon at the required depth.

[1]A graphic method for computing the total offset distance from the intersection of the axial plane with the surface, to the projection of the crest trace at the required depth has been devised. It entails the construction of curves based on the supposition that the curve of the arch of an anticline is always a parabola. Besides the possible inaccuracy of this assumption, the method is too complicated to be of much practical value and therefore has not been included here.

CONCERNING GRANITE IN WELLS IN EASTERN NEW MEXICO

By Willis T. Lee

Granite is reported in several holes drilled in search of oil in northwestern Texas and eastern New Mexico. The reports have not been seriously challenged. Possibly the inference is justified that the crystalline complex was reached but it is unfortunate that the evidence is not more widely circulated. One not familiar with local details may be pardoned for wondering if the judgment was not too much influenced by the known occurrence of granite at moderate depths along the so-called Granite ridge in Kansas. The occurrence of coarse material near the base of the Red Beds warrants the suspicion that they may be the source of the granite material found in some of the wells. If this suspicion is well founded, the drill, in place of proving the absence of oil-bearing rocks, was in reality stopped before these rocks were reached.

In order to show reasons for raising this question certain information gathered from neighboring regions must be reviewed and to do so the foundation for the classification which will be referred to must be shown for some will not agree that the unconformity at the base of the Manzano group constitutes the Pennsylvanian-Permian boundary in the southwest. The significance of this unconformity has been questioned by Bose[1], who claims that certain fossils found above the unconformity indicate Pennsylvanian age, and more recently by Beede[2] who finds the unconformity in southwestern Texas and describes it as a notable stratigraphic break. The question of the classification of rocks involved has been discussed by Berry[3] and Lee[4]. However,

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Willis T. Lee, Geologist, U. S. Geological Survey, Washington, D. C.
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[1]Bose, E., On the ammonoids from the Abo sandstone of New Mexico and the age of the beds which contain them, Am. Jour. Sci., vol. XLIX, pp. 51-60, 1920.

[2]Beede, J. W., Notes on the geology and oil possibilities of the northern Diablo Plateau in Texas, Univ. Texas Bull. 1852, 1918, published December, 1920.

the academic question raised, as to whether the boundary should be placed at a major unconformity, or, because of fossils placed at some undefined horizon where there is no physical break, need not enter here into consideration. For purposes of practical classification the usage of the U. S. Geological Survey is here followed in making the unconformity the line of separation between the Pennsylvanian and the Permian. This classification has been in use on the Survey for several years. It accords with the evidence of certain fossil plants examined by David White and of invertebrates examined by George H. Girty. It was announced in 1916 at the meeting of the Geological Society of America and published the following year.[5] It took still more definite form in 1919, when the Geological Survey officially sanctioned the reference of the Manzano group to the Permian.

It is well known that near the southern end of the Rocky mountains in northern New Mexico, thick massive limestone of Pennsylvanian age unconformably underlies red rocks of Permian and Triassic age. The lowest formation (Abo sandstone) of the Red Beds is conglomeratic. The Pennsylvanian limestone, known as Magdalena in north central New Mexico, is upturned in the mountains and has been recognized as far north as southern Colorado. The Abo thickens toward the north and becomes coarsely conglomeratic. Baker[6] states that at Mora, New Mexico, it contains "several thousand feet of arkoses." Still farther to the north, about 10 miles south of the Colorado-New Mexico line, the writer has observed conglomeratic Red Beds many thousands of feet thick, in which were large boulders of granite and other kinds of rock. Still farther north a section was measured across upturned conglomeratic Red Beds in the canyon of South fork of Purgatoire river about 5 miles north of the Colorado-New Mexico line. The conglomerates here are not so coarse as those

[3]Berry, E. W., Concerning diastrophism, Science, New Series, vol. LII, pp. 315-318, 1920.

[4]Lee, W. T., Notes on the Manzano group, New Mexico, Am. Jour. Sci., vol. XLIX, pp. 323-326, 1920.

[5]Lee, W. T., General stratigraphic break between Pennsylvanian and Permian in western America, Geol. Soc. America Bull., vol. 28, pp. 169-170, 1917.

[6]Baker, C. L., Contributions to the stratigraphy of eastern New Mexico, Amer. Jour. Sci., vol. 49, pp. 99-126, 1920.

referred to 15 miles farther south, but boulders of crystalline and metamorphic rock up to 88 inches in diameter were found at many horizons.[7] It has never been determined whether these conglomeratic beds are all Permian or are in part Pennsylvanian in age.

It is not the writer's purpose to discuss here the correlation of formations found in the little known region of northeastern New Mexico but rather to call attention to certain stratigraphic and structural relations which have thus far attracted little attention, and which should be seriously considered in interpreting the well logs of eastern New Mexico. The rocks which are most involved in these relations are those of Pennsylvanian and Permian age.

In central New Mexico the Magdalena limestone is a thick, evenly bedded formation of marine origin and where best known, changes little in character from place to place. It passes eastward underneath red sedimentary rocks of Permian age. In Texas, Oklahoma and Kansas, beds of Pennsylvanian age reappear at the surface and contain oil and gas. The continuity of the Pennsylvanian rocks to the north, both in the foothills of the Rocky mountains where they have never been adequately examined, and in the plains to the east where they are covered with younger sediments, is problematical.

The Pennsylvanian sedimentation was brought to a close in New Mexico by the elevation of mountains which the writer has termed the Ancestral Rocky mountains. The Pennsylvanian strata were upturned in these mountains, eroded, and probably in some places entirely removed. The post-Pennsylvanian unconformity has been recognized in so many places over a wide zone extending from Texas to Utah that it seems appropriate to regard it as a major unconformity. Little can be said now of the area occupied by the Ancestral Rockies, for they were worn down and their roots covered by younger sediments. But as the fragmental material derived from them is thousands of feet thick, it is obvious that these mountains were of no mean proportion. It

[7]Lee, W. T., Raton Mesa and other regions of Colorado and New Mexico, U. S. Geol. Survey Prof. Paper 101, p. 41, 1907.

is possible that the Granite ridge of Kansas is a part of this mountain system, although Moore[8] regards the ridge as a feature of the pre-Cambrian floor. As this ridge is somewhat nearer the Ozarks than the Rocky mountains, the temptation is strong to associate it with these rather than with the Rocky mountains. However, the extent of the post-Pennsylvanian movement has not been determined. It would be of scientific interest as well as of economic importance to determine whether the Granite ridge resulted from folding during the post-Pennsylvanian mountain-making epoch or stood as an upland ridge during early Carboniferous time. It would be of interest also to know if the Pennsylvanian rocks to the west of the ridge constitute in any measure the filling of embayments or are infolded remnants truncated by post-Pennsylvanian erosion.

The sediments derived from the Ancestral Rockies are unusually thick and coarse in the eastern foothills of the northern New Mexico Rockies, where they consist of conglomerate and arkose thousands of feet thick and contain great numbers of large boulders of granite and other crystalline rock. The coarse conglomerate constitutes the lower part of the Red Beds and is supposed to be of Abo age, that is, basal Permian. It is overlain by finer grained red sediments, the upper part of which is known to be Triassic in age. The coarse material near the base of the Permian is of chief importance in the present consideration. The thick beds upturned in the mountains plunge steeply eastward underneath the plains. About 100 miles from the foothills the drill has passed through considerable thicknesses of Red Beds and stopped in material reported as granite. The question may be raised: Is this material from the crystalline complex which underlies the Paleozoic rocks or is it from conglomerate near the base of the Permian? Although the question cannot now be answered it is not out of reason to suppose that the thick beds of arkose may extend eastward to these well localities. Furthermore, the presence of coarse material in late Pennsylvanian and Permian sedimentary rocks in Oklahoma suggests that arkosic material in some places may have been derived from local sources.

If the Permian conglomerates of the Rocky mountains do extend eastward into Texas, or if granitic debris in the lower part of the Red Beds was derived from a local source, it is possible that the "granite" reported from some of the wells comes from this arkose and that the occurrence denotes, not that oil-bearing Pennsylvanian is absent but rather that the drill did not reach the oil-bearing rocks. There are many lines of evidence bearing on this question, and possibly there is enough scattered information to settle it, but the writer has not yet found sufficient evidence to convince him of the absence of the oil-bearing Pennsylvanian from northeastern New Mexico.

The most advantageous place that the writer knows in northeastern New Mexico for testing the presence of granite near the surface has never been occupied so far as known. This is in the canyon of the Dry Cimarron a few miles west of the Oklahoma line.[9] Here the Triassic rocks were arched, truncated, covered with Jurassic and younger sedimentaries and finally exposed again when the canyon was cut. The amount of arching and subsequent erosion is not known, but the size of the dome indicates that an appreciable thickness of strata was removed from the top of the Red Beds. It is possible that these beds are thin enough here for the drill to penetrate them and to test definitely the question whether they are underlain by granite or by sedimentary rocks older than Red Beds.

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[9]Lee, W. T., The canyons of northeastern New Mexico, Jour. Geog., vol. II, p. 70, 1903.

I am informed by those who were more fortunate than I in being able to attend the Tulsa meeting of the American Association of Petroleum Geologists, that many facts not generally known before were made public These facts tend to strengthen the inference that the granite is nearer the surface than I had supposed and that oil-bearing Pennsylvanian rocks are not present in some places. The new facts change the problem but do not entirely solve it. The extent and shape of the buried highland remains unknown. Also it is probable that Permian arkose is present in many places. This arkose is likely to be encountered by the drill and perhaps wrongly interpreted as indicating the basement complex. Furthermore, if a granite highland existed in or near northwest Texas in Pennsylvanian time, or if a highland was formed there at the close of the Pennsylvanian, it may have supplied arkose which buried surrounding rocks of Pennsylvanian age. Such arkose might readily be interpreted as indicating the base of the sedimentary series.

The new information brought out at the meeting emphasizes two important needs: (1) material from wells should be examined microscopically by experts competent to distinguish between fresh granite and weathered rock such as might be expected from arkose, and (2) it is highly desirable that information which interets so many people be more widely circulated than it has been.

OIL DEVELOPMENT AND PROSPECTS IN TENNESSEE

BY L. C. GLENN*

Deep well drilling began in Tennessee about a century ago. In the early days this drilling was for salt brine, and while an occasional well in the first half of the last century produced some oil, oil was not then desired and it was only after the Civil War that definite search for oil began. Most of this drilling was on the eastern part of the Highland Rim in Overton and other counties southwest of it where the surface rocks are of the Mississippian age. Oil was obtained at shallow depths either in the base of the Mississippian or just beneath the Devonian black shale. In some cases the oil was evidently in crevices and the wells were soon exhausted and abandoned. Some drilling was done in the Central basin region in Ordovician rocks but only a few oil shows or gas pockets resulted from this. Interest was revived in 1892 by finding oil in the Spurrier district of Pickett county. A number of wells were drilled in the next few years and a pipe line was laid from the Wayne county, Kentucky, fields and production was maintained until 1906. Production then ceased until the discovery of oil in 1915 at Oneida in Scott county in fissures in the St. Louis limestone at a depth of about 950 feet. This find proved a disappointment but led to other drilling in that region and the next year oil was found in the southern part of the same county at Glen Mary, in the St. Louis limestone at a depth of 1232 feet.

Oil occurs here in fissures in the limestone. Where these are very open, production is free but wells are short lived. Where fissures are not so open wells start at about ten barrels and have held up remarkably well. There is very little gas along with the oil, though the same rocks yield several million feet of gas from a well or two a couple of miles away.

Fissuring in the Glen Mary region is neither universal nor always at the same horizon in the St. Louis but varies rapidly

*The writer wishes to acknowledge his indebtedness to Mr. W. A. Nelson, State Geologist, for data on some of the very recent drilling.

in both respects and yet the middle part of the St. Louis may generally be regarded in that region as a fissured petroliferous horizon. There is no specially favorable local structure at Glen Mary so far as is known.

The surface rocks about Glen Mary are Pottsville sandstones and shales in which any detailed local structure if it existed would be difficult or impossible to determine from surface examination. The general surface of the St. Louis is that of a long monocline rising slowly westward from beneath the deepest part of the coal basin to the east. To the west of Glen Mary no flattening or reversal of dip is known though there may be a closing, or rather a lack of development there, of the fissures in the St. Louis limestone which have made the accumulation of oil at Glen Mary possible, and whose absence farther west has prevented the oil from migrating westward.

Although there has been considerable drilling activity in many other widely scattered parts of the state for several years, yet the Glen Mary field remained until recently the only oil producing area in Tennessee. Recently, however, oil has been found in the northern edge of Sumner county, just across the line from the Allen county, Kentucky, field. Production here is from Silurian or Devonian limestones just beneath the Devonian black shale, and the area in which there are but three or four wells at present, is an extension of the Allen county field.

In Overton, Pickett, and Fentress counties there has been considerable drilling recently and several wells have found oil and promise to be producers when finished and put to pumping. The most promising one of these is in Pickett county and gets its oil from the Ordovician. The region is just south of Wayne county, Kentucky, where oil was found some years ago in the Sunnybrook pool in the Ordovician. The horizon is possibly the same as the Sunnybrook.

One may say, then, that there is now production, either actual or in sight, in three places in the state, and may ask what are the prospects for extending the area of production. In attempting to give an answer to such a query it is necessary to characterize briefly the possible oil bearing forma-

tions of the state and indicate their areal distribution.

The Cambrian may be excluded and with it the basal part of the Ordovician, here represented by the upper part of the Knox dolomite. The remainder of the Ordovician is composed of limestone or shale. The limestones are only locally porous or fissured and while they have small quantities of oil and gas in the Central basin region, give no promise of commercial production there. It is possible that the Ordovician may contain oil in commercial quantity in the Overton-Pickett-Fentress county region though the writer does not regard the chance as being a very favorable one.

The Silurian is locally absent or quite thin in certain parts of the state. Where present it is largely limestone, but with subordinate shales. The limestone is more apt to be porous than is the Ordovician limestone. It is usually impossible in well cuttings to separate it from Devonian limestones of practically the same texture and color, which, like the Silurian, occur in some places and are absent in others. These two limestones may be regarded as a unit for oil purposes. Together they vary from a few feet to 100 feet or, exceptionally, 150 or 200 feet, in thickness and are overlain by the Chattanooga black shale which is in most places 30 to 60 feet thick but may vary from nothing to 150 feet. Over 90 per cent of the Kentucky oil production is derived from these Silurian and Devonian limestones close beneath the black shale, and as these rocks are continuous in the Highland Rim region in Tennessee with their Kentucky areas, and are very similar lithologically and structurally, they should furnish favorable areas for oil production here also. Numerous locally favorable structures exist in them. As in much of the Kentucky area, these are usually small and difficult to locate because of poor exposures. Favorable areas include the eastern margin of the eastern Highland Rim where these rocks are rising westward toward the Nashville dome from beneath the synclinal trough of the Cumberland coal basin. Another favorable region is on the western and northwestern Highland Rim as they start to dip beneath the Mississippi embayment and toward the western Kentucky coal basin respectively. Considerable drilling has been done on both

the eastern and western Highland Rim, much of it without regard to structure, but so far the recent strikes in Sumner county mentioned above, are the only successful wells. Other drilling is in progress now and the writer knows of no geological reason why additional productive areas may not be discovered in both these regions.

The Mississippian consists of limestones and shale with at least one sandstone, the Cypress or Hartselle. Rocks of this age form the surface of the Highland Rim and only exceptionally have oil shows in their basal portion on the Highland Rim. To the east of the Rim under the cover of 800 to 1200 feet of Pennsylvanian beds they furnish production at Glen Mary as described above. Under much of the northern half of the Cumberland plateau and under the broader portion of the southern half, the fissured middle portion of the St. Louis limestone should yield oil under favorable structural conditions just as it is now doing at Glen Mary. Practically no drilling has been done in this plateau area. These rocks may be reached on the plateau at from 800 to 1200 feet and the base of the Chattanooga black shale at 200 to 400 feet farther.

The Pennsylvanian sandstones and shales which make the surface of the Cumberland plateau have a maximum thickness of 1000 to 1200 feet. The writer does not look for them to contain more than shows of oil and gas, unless possibly near the Kentucky line in Scott county, since not far northeast of there in Knox county, Kentucky, oil has been obtained from the Pottsville at several horizons.

Cretaceous rocks form the lowest part of the Gulf embayment deposits of western Tennessee and are overlain by Tertiary beds. Both consist of unconsolidated sands and clays and attain a maximum thickness of 2500 to possibly 3500 feet along the axis of the trough, which is presumably about along the western border of the state. The Cretaceous rocks of this area are of the same age and are continuous with those now yielding oil and gas in Louisiana and Arkansas. Wells at Memphis and some thirty miles north of there in Tipton county have gone between 2500 and 3000 feet in these embayment deposits and report shows of oil or gas. At Reel-

foot lake in the northwest corner of the state several wells have pentrated these deposits 1500 to 1800 feet with reported shows of both oil and gas in some and none in others. The writer does not regard conditions in the Reelfoot region as promising. It is in about the lowest part, structurally, of the spoon shaped northern end or tip of the embayment area; its major structure must be synclinal; and its unconsolidated beds rising to the surface on one or more sides near by, are most probably water logged. The old Paleozoic hard rock floor at Reelfoot was broken and faulted in the great earthquake of 1811-12, and had suffered similar movements for a long period before then, and fissures in the unconsolidated embayment rocks poured forth water and sand but no oil.

It is possible that these unconsolidated embayment rocks may contain oil somewhat farther south in western Tennessee. Their structure is largely hidden by a blanket of surficial sands so that drilling must be largely a matter of chance, and success mainly the result of luck. The Paleozoic floor beneath the embayment deposits may possibly contain oil, though a profound erosional unconformity separates the Mississippian, the youngest of these rocks, from the Cretaceous, the oldest of the embayment deposits, and from surface examination there is no possible way of determining either the age, lithologic character or structure of the rocks of the old floor. A well that strikes this old floor without getting oil should be continued far enough into the floor to determine its age and oil possibilities.

RELATION OF THE BASE OF THE RED BEDS TO THE OIL POOLS IN A PORTION OF SOUTHERN OKLAHOMA

By George E. Burton.

INTRODUCTION

It is common knowledge among oil producers in southern Oklahoma that oil is usually found where the Red Beds are comparatively thin and that dry holes are found where they are comparatively thick. It was therefore thought worth while to show on the same map the oil pools of this area and isopachous (equal thickness) contours drawn at the base of the red material shown in all the available logs of wells in the area. The accompanying map (Plate I) is the result.

The writer is indebted to Mr. A. W. McCoy under whose directions this work was carried on for the Empire Gas and Fuel Company, and to Dr. L. C. Snider who permits this report to be made public.

THICKNESS OE RED BEDS

The map shows that there is a decided thinning of Red Beds over the oil pools, and a decided thinning in one area where no oil has been found. The thin Red Beds can be divided into three distinct areas, all of which trend in a northwest-southeast direction. On one of these areas is located the Two Four, the Fox, the Graham, and the Wheeler pools, on another the Healdton and the Hewitt pools, and on the third no production has yet been found. Over parts of the Healdton and Hewitt pools the Red Beds are less than 200 feet thick, over parts of the Wheeler pool less than 400 feet, over the Graham pool less than 600 feet, and over the Fox and Two Four pools less than 1000 feet. Between the Fox and Healdton pools, the Red Beds reach a thickness of 2200 feet and between the Healdton pool and the area of thin Red Beds in T. 7 S., R. 4 W., they have a thickness of 2400 feet. It

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seems, then, that the thinning of Red Beds over the oil pools in this portion of Oklahoma is an established and significant relation. It is the purpose of this paper to point out the geological reason for this thinning of the Red Beds.

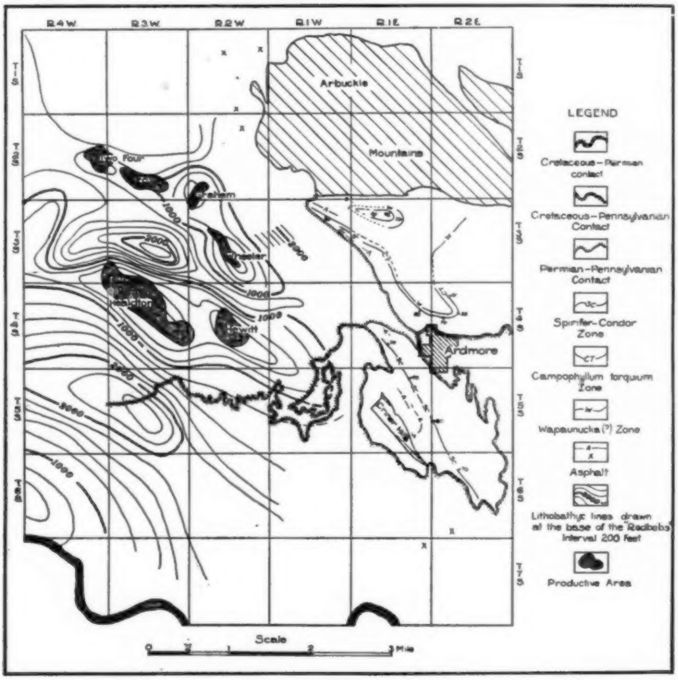

Fig. 1. Map of a portion of southern Oklahoma showing location of oil fields and thickness contours of Red Beds.

There are two facts that must be considered in explaining the thinning which has been mentioned, (1) lack of parallelism between the base of the Red Beds and the strata from which the oil originates, and (2) the influence of erosion in removing the tops of the folds in which the oil occurs.

The oil fields in this area are located on topographic "highs." This is especially true of the Fox field, where the surface contours check pretty closely with the structure con-

tours as mapped from surface outcrops. The thinning of Red Beds due to erosion is probably very slight.

STRUCTURE OF PERMIAN ROCKS

During the summer of 1919 W. L. Goldston Jr. and Chas. J. Wohlford studied in detail the outcrops of formation in the vicinity of Ardmore between the Arbuckle mountains and the Criner hills. D. K. Greger made extensive fossil collections from which he was able to place the 15,000 to 18,000 feet of strata in this area as lower to middle Pennsylvanian in age. The rocks of the Glenn are intensely folded, the folding consisting of strong dips southwest from the Arbuckle mountains, a prominent steeply folded anticline in T. 3 S., R. 1 E., T. 4 S., R. 1 E., and T. 5 S., R. 2 E., a syncline trending northwest-southeast through the city of Ardmore and rather steep dips northeast from the Criner hills. The steep dips just south of the Arbuckle mountains apparently conform to the dips in the older rocks and no apparent unconformity between lower Pennsylvanian and Mississippian could be determined. All this indicates that the mountain making movement which produced the Arbuckle mountains occurred later than middle Pennsylvanian time. The Arbuckle mountain folding extended over a wide area to the northeast and southwest. The presence of Arbuckle limestone in a well in sec. 35, T. 6 S., R. 3 W., and granite in a well nine miles north of St. Joe, Montague county, Texas, indicates that the Arbuckle mountain folding in a northeast-southwest direction in this area is more than 75 miles wide. Since the axes of known folds, not only in the Arbuckle mountains, themselves, but in the Glenn formation trend northwest-southeast, this folding in Pennsylvanian rocks, no doubt extends many miles in a northwest-southeast direction, and is no doubt present in the area of the oil fields indicated on the map.

It seems probable, then, that there is present under the oil fields of this area closely folded strata of not only Ordovician age, as pointed out by Powers[1], but also of lower Pennsylvanian age.

[1]Powers, Sidney, Age of Oil in Southern Oklahoma, American Institute of Mining and Metallurgical Engineers, Vol. LIX, page 571.

The asphalts which occur in the vicinity of Ardmore are found in the lower one-half of the Pennsylvanian strata. If these asphalts represent the horizons of the original source of the oil, it is apparent that considerable folding or faulting would be necessary to bring these horizons within reach of the drill.

These considerations indicate at least that there were sizable ridges, made up of strata anywhere from Cambrian to middle Pennsylvanian in age, present when the Red Beds were laid down. The red material, consequently reached its greatest thickness in the valleys between the ridges.

UPPER PENNSYLVANIAN STRATA

During the summer of 1919 E. H. Bauman traced the Franks conglomerate at Sulphur northward into the Seminole conglomerate at Ada. The Seminole conglomerate, which is the most prominent of many conglomerates north of Ada extends north across Seminole county and into the edge of Okfuskee county[2].

Beede[3] has placed the approximate eastern limit of the Permian near Tecumseh, in Pottawatomie county. The Seminole conglomerate outcrops near the town of Seminole about 15 miles east of this point. Assuming that the strata above the Seminole dip west at the rate of forty feet to the mile, there is, then, some 600 feet of Pennsylvanian strata which in the vicinity of Ada lies unconformably over older Pennsylvanian strata. There is, then, in the vicinity of Sulphur to the north and west of the Arbuckle mountains a considerable section of late Pennsylvanian sediments which are probably conformable with overlying Permian strata. It may be that equivalent strata are present in the vicinity of the oil pools in the area south of the mountains. This really indicates very complex conditions underground in the oil pools. Oil might occur in the comparatively horizontal strata late Pennsylvanian to Permian in age or in the comparatively steep dipping strata of early Pennsylvanian or older. At any rate there is a lack of parallelism between the base of the Red

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[2]McCoy, A. W., Personal communication.
[3]Beede, J. W., Okla. Geol. Survey, Bull. 21, p. 22, fig. 1.

Beds and the original source of the oil. Thin Red Beds probably indicate up-folds in middle and lower Pennsylvanian and older rocks.

SUMMARY

The mountain making movement which produced the Arbuckle mountains occurred at least later than middle Pennsylvanian time. In the area of the oil pools of southern Oklahoma there may be present closely folded strata Cambrian to middle Pennsylvanian in age. The more nearly horizontal rocks are Permian and late Pennsylvanian or older. There were present when the Red Beds were lain down ridges of closely folded strata of middle Pennsylvanian age and older, the red material reaching its greatest thickness in the valleys between the ridges.

REGULARITY OF DECLINE OF OIL WELLS IN CALIFORNIA

By R. P. McLaughlin

The laws governing the rate of decline of production of oil wells have been intensively studied in the past six years and considerable progress has been made since investigators have adopted the plan of systematically arranging the data furnished by past production. Particularly gratifying results have been obtained by the practice of publishing tentative conclusions together with the evidence upon which they were based. Successive investigators have added new ideas until we are now in possession of some general principles which can be applied to economic estimates. The work of J. O. Lewis, C. H. Beal and E. D. Nolan[1,2] has been specially valuable in evolving rules which interpret and amplify some facts which were previously noted by the writer[3].

The regularity in decline of the average daily production per well in large fields is one of the most striking features of graphic statistics. This striking feature may be noted in many and probably all oil fields. It is clearly shown in all of the accompanying diagrams of California fields. In the record of the Kern River field, for instance, the points representing daily well production appear as three practically straight lines, the intersections or angles occurring at the years 1907 and 1914. Where a record does not appear as a single straight line it is necessary to find some regularly shaped curve which may be reasonably projected for use in estimates of future production. A curve is necessary because it would be difficult or impossible to prophesy either the position or degree of angularity in a series of projected straight lines.

[1]Lewis, J. O., and Beal, C. H., Some new methods for estimating the future production of oil wells, Am. Inst. Min. Eng. Bull. 134, pp. 477-505, Feb., 1918.

[2]Beal, C. H., and Nolan, E. D., Application of law of equal expectations to oil production in California, Am. Inst. Min. Met. Eng., Bull. 152, pp. 1237-1245, Sept., 1919.

[3]McLaughlin, R. P., and Waring, C. A., Petroleum industry of California, Cal. State Min. Bur., Bull. 69, pp. 58, 169, 1914.

The curve shown in Figure 1 is found to fit the conditions in not only one but most of the California fields. Because the curve may be useful in some general estimates and because it invites further study in search of explanations for

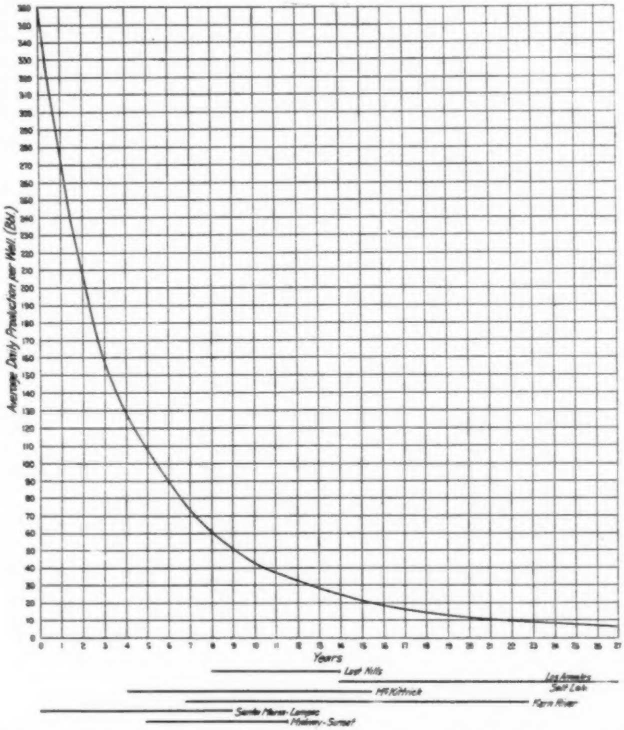
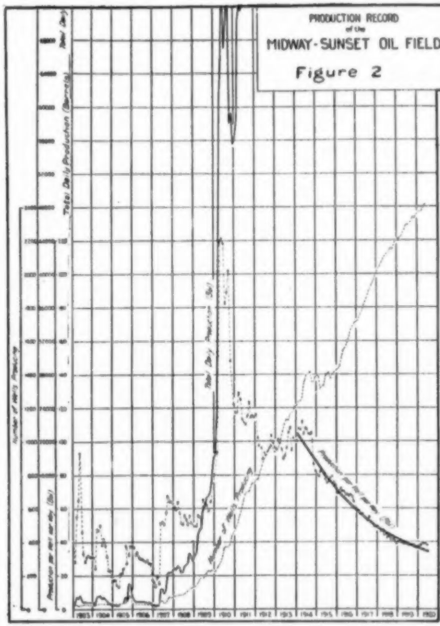
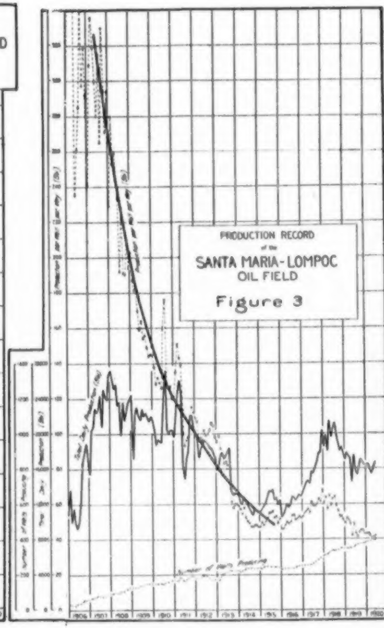
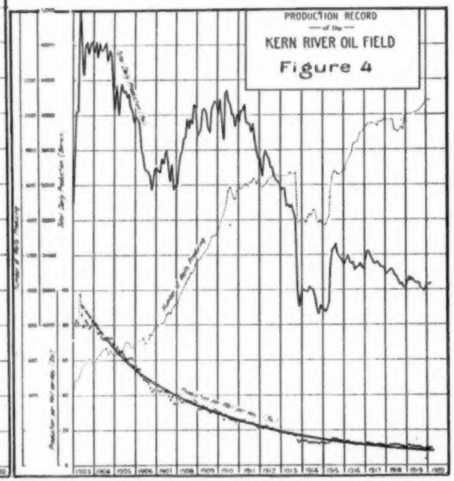


Fig. 1. Curve showing rate of decline of oil production of an average well in several California fields.

the coincidence, its publication seems justifiable. The method of constructing this curve is similar to that used by Beal and Nolan in constructing a "family curve" from records of single wells. Instead of using graphic records of production of single wells, the graphic records of entire fields showing the average daily production per well are used. A fairly regular curve can be drawn upon each of


PRODUCTION RECORD
of the
MIDWAY-SUNSET OIL FIELD
Figure 2


PRODUCTION RECORD
of the
SANTA MARIA-LOMPOC
OIL FIELD
Figure 3


PRODUCTION RECORD
of the
KERN RIVER OIL FIELD
Figure 4

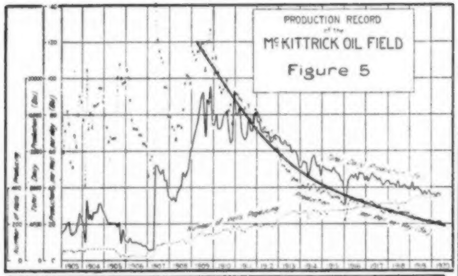
the field diagrams so that it closely conforms to the points representing average production per well per day. When tracings of these curves are superimposed and shifted horizontally along the zero or base line they are found to be so similar to each other that they clearly indicate the shape of a composite curve which will closely conform to all the single curves. The parts of the composite curve which are taken directly from records of the various fields is shown by the horizontal lines at the bottom of the drawing. It will be noted that throughout almost its entire length the curve is supported by several separate records of facts.

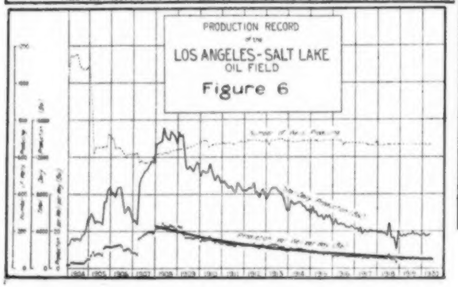
The extent to which the curve fits various conditions and localities in California is shown by its position on the production diagrams of the following fields: Midway-Sunset (Fig. 2), Santa Maria-Lompoc (Fig. 3), Kern River (Fig. 4), McKittrick (Fig. 5), Los Angeles-Salt Lake (Fig. 6), Lost Hills-Bellridge (Fig. 7).

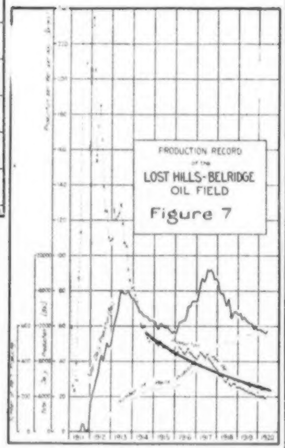
These six fields contain about 70 per cent of the producing wells of the state and contribute about 55 per cent of the total production of the state. The production diagrams of the various fields are compiled from monthly statistics published by a large marketing company. The statistics are accurate within two or three per cent.

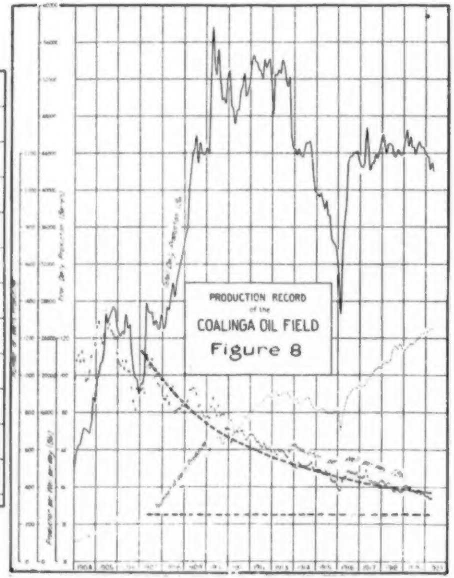
The composite curve fails to fit the record of only one field, namely Coalinga (Fig. 8). The production per well per day in this field has an unusually slow rate of decline, which may possibly be due to the care which has been given to wells to prevent damage by water. This field contains about 13 per cent of the producing wells of the state and contributes about 15 per cent of the total production of the state. It should be noted that when the curve is moved vertically it fits the production record for thirteen years, following 1906. This arbitrary shifting of the curve places its line of zero production about on the twenty-five barrel line of the field record.

There are only two other principal fields in California, Whittier-Fullerton and Ventura-Newhall. Their records are not pertinent to this discussion and the diagrams are not presented, because the statistics embrace so many separate


PRODUCTION RECORD
of the
McKITTRICK OIL FIELD
Figure 5


PRODUCTION RECORD
of the
LOS ANGELES-SALT LAKE
OIL FIELD
Figure 6


PRODUCTION RECORD
of the
LOST HILLS-BELRIDGE
OIL FIELD
Figure 7


PRODUCTION RECORD
of the
COALINGA OIL FIELD
Figure 8

pools that the figures are not significant. In the case of the Whittier-Fullerton field the daily well production appears to increase, due to the fact that several new and highly productive fields have from time to time been added to the records of the older pools. Much the same applies to the record of the Ventura-Newhall field. Therefore the fields here considered contain about 83 per cent of the producing wells of the state and contribute about 70 per cent of the total production of the state.

The rate at which a field is developed might be expected to affect the rate of decline in average well production. Rapid development should check the decline unless the wells were drilled so closely as to interfere materially with each other's production. In order to consider the effect of rate of development, the number of producing wells in each field is graphically shown in Figure 9 together with the composite curve. The record of the number of wells in each field is shown only for the period of time covered by the portion of the curve taken from the field in question.

It will be noted that in each field development progressed rapidly until the production of the average well fell to about twenty barrels daily, and after that time the development increased very slowly. From January 1918 until July 1920, there were 1453 wells completed in California with an average initial daily production of 209 barrels.

Evidence that the rate of field development probably does not affect the rate of decline in well production, is afforded by the graphic records of the Kern River and Coalinga fields. In the Kern River field development temporarily stopped in 1910 but there was no corresponding drop in average well production. In the Coalinga field development was arrested in 1913 without affecting the rate of decline in average well production. Further evidence is afforded by the record of the McKittrick field which was developed slowly, eleven years being consumed in doubling the number of wells, nevertheless the field record fits the composite curve. It therefore seems probable that the rate of field development does not greatly affect the shape of the composite curve, and if this is true it would indicate that wells in most of the California

fields have not been drilled too close to each other. In the fields considered there is an average of 11.6 acres of proved oil land per producing well, and for the entire state the average is 10.3 acres.

In order to illustrate the significance of the rate of decline

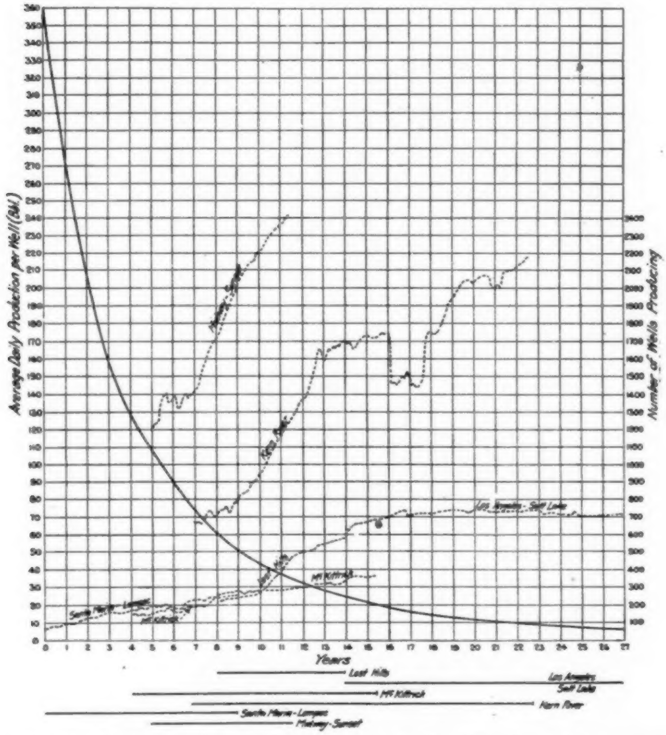


Fig. 9. Curve showing rate of decline of oil production of an average well in several California fields and diagrams showing the number of producing wells in each field.

of well production in very large numbers of wells the production record of California since 1903 is presented in Figure 10. Since 1914 the regularity of decline in daily well production is specially notable.

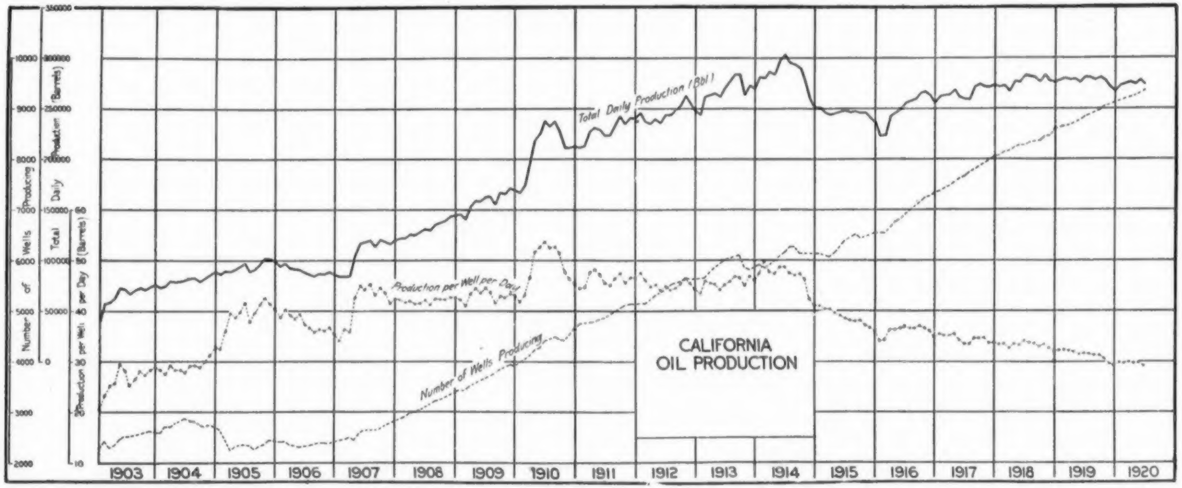

CALIFORNIA
OIL PRODUCTION
Total Daily Production (Bbl)
Production per Well per Day
Number of Wells Producing
Number of Wells Producing
Total Daily Production (Barrels)
Production per Well per Day (Barrels)
1903
1904
1905
1906
1907
1908
1909
1910
1911
1912
1913
1914
1915
1916
1917
1918
1919
1920

Fig. 10

THE OIL-BEARING HORIZONS OF WYOMING

By K. C. Heald

INTRODUCTION

Wyoming holds leading place among the oil producing states of the Rocky mountains. One of the first to attain prominence, the state has since yielded a steadily swelling volume of oil, which has gone far toward supplying the increasing needs of the Rocky mountain area and to relieve the eastern and Pacific coast fields of a demand they could meet with difficulty, if at all. In spite of this, and the conceded importance of the district, there is astonishingly little detailed information available to the man who desires precise knowledge about the conditions that affect the oil-bearing possibilities of large portions of the state. It is true that excellent reports on stratigraphy, structure, and economic geology have been published and are available, but a considerable proportion of these do not supply the precise data that present methods of prospecting and development demand. This is particularly true when the oil-bearing horizons of the state are considered. Even the correlation of the oil-yielding horizons in many of the fields is in doubt, for there are large unmapped areas over which the geologist must "jump" in his office study of the producing beds, and in many of the mapped areas the oil measures are burdened by a load of Tertiary sediments which absolutely prevent the continuous tracing of the productive horizons.

The published data relating to the oil-bearing formations are found, for the most part, in the numerous publications of the United States Geological Survey and of the Wyoming Geological Survey, with a few articles in technical and scientific journals. The total would not make a very long list, but there is ample material to furnish solid foundation for future work. The work which has been done furnishes knowledge concerning the thicknesses of the different producing beds in various fields of the state; the positions of the beds in the stratigraphic sec-

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tions of many of the producing fields, as well as in much of the unproductive intermediate territory; correlations between closely adjacent fields and in some large districts that can be accepted without question, and other correlations which may be correct but which will need verification; the physical characters of the oil-containing beds in a few of the fields; and the relations which these beds bear to the strata in which the petroleum probably originated in a great many of the districts.

Oil or gas is found in Wyoming in beds ranging in age from pre-Cambrian to Tertiary, and every period between and including the Carboniferous and the Tertiary has at least one formation that is known to contain oil or gas within the boundaries of the state, although the mineral may be in such small quantity as to be commercially valueless. The various known oil-bearing horizons are discussed below in stratigraphic sequence.

PRE-CAMBRIAN

A single instance of oil in pre-Cambrian granite is recorded by L. W. Trumbull[1]. The oil occurs as an asphaltic residue, black, gummy, and too thick to flow except on hot days, along what are believed to be fault planes in the granite on Copper mountain near the old settlement of Depass in Fremont county. There is, of course, no question of the oil being indigenous in the bed where it now occurs. The explanation of the occurrence offered by Trumbull is that the oil originated in the Embar formation, and accumulated on a dome underlain by the Copper mountain granite core. Further uplift fractured the sediments and permitted the oil to work down along the fault planes into the granite, the water receding before the oil as uplift continued.

CAMBRIAN

Deadwood formation.—Oil residue is said to occur in the Deadwood formation, of Upper Cambrian age, about 8 miles northwest of Lysite[2] in Fremont county, on the south limb of Owl creek canyon. The middle member of the Deadwood sand-

[1]Trumbull, L. W., Petroleum in granite: Wyo. Geol. Survey, Bull. No. 1, 1916.

[2]Personal communication from C. A. Fisher.

stone is said to be heavily saturated, but no theory has thus far been advanced to account for the occurrence of the petroleum in the Cambrian rocks. It seems altogether unlikely that the oil originated in these beds, for they have been so altered that any original oil content would have long since disappeared. The proximity to the oil occurrence in the granite of Copper mountain suggests that the same explanation will apply to both occurrences.

CARBONIFEROUS

MISSISSIPPIAN

Madison limestone.—The Madison limestone, of Mississippian age, has never demonstrated an ability to yield oil in commercial quantity, although there is evidence indicating that commercial accumulations in this formation are at least possible. In a number of localities it is sufficiently bituminous to emit a strong odor of oil when freshly broken, and it may even be discolored by black asphaltic material, and have small cavities and fissures filled with solid hydrocarbons[3]. It is, moreover quite fossiliferous in places, showing that conditions during its deposition favored the existence of abundant life, among which might be petroleum-yielding organisms.

The Madison appears well suited to serve as a reservoir bed for any oil that might originate in it. Quite commonly it is raggedly porous, where percolating waters have dissolved cavities ranging from large caverns to microscopic apertures, and should yield wells of large initial volume if oil actually occupies some of these areas of high porosity. Its ability to contain and yield liquid was probably well illustrated on the Tisdale anticline, in T. 4 N., R. 81 W., where a well which is believed to have penetrated its upper surface gave a flow of hot water estimated at 75,000 barrels per day.

The type locality of the Madison limestone is in the Madison mountains of west-central Montana, to the west of Yellowstone National Park. It has been traced southeastward into Wyoming, and is splendidly exposed in the mountains that rim

[3]Washburne, Chester W., Gas fields of the Big Horn Basin: U. S. Geol. Survey, Bull. 340, p. 361, 1908.

the Big Horn basin and also in the mountain ranges of western Wyoming. The Pahasapa limestone of the Black Hills is believed to be contemporaneous with the Madison and there seems to be no reason for assuming that the two formations do not meet under the Powder river basin. The Guernsey formation, exposed near Guernsey, Platte county, in southeastern Wyoming, apparently represents the same time. Similarly, the basal portion of the Casper formation in the Douglas field of central Wyoming has yielded Mississippian fossils[4] (probably Madison forms, according to Dr. Girty), although geologic work to date indicates that the Casper formation near the south line of the state may be of Pennsylvanian age throughout. It may therefore be deduced that limestone of Madison age underlies all of Wyoming with the exception of a U-shaped area in the southeastern portion of the state including the southern parts of Carbon and Rawlins and all of Laramie counties. It is recorded as approximately 1,600 feet thick in the northwest part of the state[5] and thins to little more than 500 feet near the east line of the state if the Pahasapa is actually the continuation of the Madison. In Carbon, Rawlins and Laramie counties it feathers down to almost nothing if, indeed, it is not entirely missing. This thinning may be due either to the history of deposition or to erosion. If it can be established that erosion is responsible throughout, the potential value of the formation as an oil producer will be reduced, as deep weathering and the action of percolating waters may well have resulted in the dissipation or conversion into unusable residue of much of the original oil content.

PENNSYLVANIAN

Tensleep sandstone.—The Tensleep sandstone of Pennsylvanian age is so related stratigraphically to "mother rocks" of petroleum that in many places it cannot be considered a probable container of oil. It directly overlies the Amsden formation (where present), which is composed largely of red shale, and

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[4]Barnett, V. H., The Douglas oil and gas field, Converse Co., Wyo.; U. S. Geol. Survey Bull. 541, p. 56, 1912.

[5]Hague, Arnold, U. S. Geol. Survey Geol. Atlas, Absaroka folio (No. 52) p. 3, 1899.

which cannot be regarded as a possible source of petroleum. In the Black Hills the Minnelusa sandstone, which by some is regarded as the equivalent of the Tensleep, underlies a red-bed series—the Opeche formation. The chances of the Tensleep sandstone receiving oil by migration from underlying beds would be limited to areas where faulting has furnished channels through the red strata, and to regions where the red beds are absent. The first of these conditions is so prevalent in the folded regions of Wyoming, and there are such broad areas where the second also obtains, that, from a theoretical point of view, it would not be justifiable to fail to consider the Tensleep as a possible reservoir bed, even where its chance of holding oil is limited to such as may have originated in the Madison limestone. Such a limitation does not hold, however, for the Embar limestone, immediately overlying the Tensleep, is known to contain notable amounts of oil in many places.

Seepage oil has been reported from the Tensleep sandstone at a number of localities in central Wyoming, and the promise of the surface showings has been substantiated by wells drilled on the Pine mountain dome in central Natrona county, where a heavy black oil was encountered. Initial productions as high as 200 barrels per day have been reported. In the Rocky Ford "field," Crook county, on the western edge of the Black Hills uplift, heavy black oil occurs both in wells and in seeps in the Minnelusa sandstone. Oil in paying quantity has not been found in the Rocky Ford area, although some of the oil-impregnated sands indicate the existence, at some previous time, of extensive pools.

Evidence now available makes it appear that the Tensleep, or a formation approximately the same in character and in stratigraphic position, such as the Minnelusa sandstone of northeastern Wyoming, the Weber formation of southern Wyoming, and parts of the Casper formation of southern Wyoming extends under the entire state. There will undoubtedly be areas where it is absent or extremely thin, but these promise to be very limited in extent. The formation seems to be much thinner in central and north-central Wyoming than it is either to the east or west, but this difference may be erosional rather than de-

positional. That this is actually the case is indicated by many abrupt changes in its thickness.

PENNSYLVANIAN, PERMIAN AND LOWER TRIASSIC

Embar limestone.—The Embar limestone of the Big Horn basin probably underlies the equivalent of the Minnekahta limestone of the Black Hills, and possibly of the upper part of the Casper formation of the Laramie basin. It is known to include equivalents of the Park City (Pennsylvanian and Permian), and the Phosphoria (Permian), formation of the western part of the state.

This is the oldest of the oil-containing beds of Wyoming that are yielding important amounts of oil at the present time. In most of the localities where the formation is exposed it is easy to find layers which yield a noticeable bituminous odor when the rock is freshly broken. Twelve of 16 samples from the Phosphoria formation that were tested for oil by dry distillation and by extraction yielded traces of oil ranging from a few drops to 4½ gallons to the ton. In places the Minnekahta limestone of the Black Hills is noticeably bituminous. Oil seeps from the top of the Casper formation in the Douglas district, and from various horizons in the Embar at other places. The promises of these showings are fulfilled in the fields near Lander, Hamilton dome and Warm Springs dome near Thermopolis in the Big Horn basin, Maverick Springs anticline in Hot Springs county south of the Owl Creek mountains, Bolton creek in Natrona county, and possibly some other areas.

Although the Embar is called a limestone, and is dominantly and in places entirely made of limestone, it is quite variable in character. In places beds of sandstone are present, and in others the formation includes shales. Throughout central Wyoming it includes considerable thicknesses of phosphate rock. A number of stratigraphic sections show a very appreciable amount of red shale and limestone which some observers believe is more appropriately included in the Embar than in the overlying Chugwater formation. There can be little doubt, however, that the petroleum which is commonly present originated in the limestone portion, for the associated shales, whether intercalated with the limestone beds or belonging to

immediately overlying or underlying formations, appear to be practically barren of original organic matter.

If the tentative correlations suggested at the beginning of the description of the formation are found to hold, the Embar is present practically everywhere under the state of Wyoming except where it has been stripped off along the crests of the mountain uplifts, or in limited areas where it has been removed by erosion. Whether or not it can be considered potentially oil-bearing wherever it is within drilling depth and not too highly altered, has not been demonstrated. However, the fact that oil showings occur in it from Idaho on the west to extreme eastern Wyoming on the east, and from Utah on the south to Montana on the north, certainly furnishes sufficient incentive for thorough testing where it can be done without prohibitive expense.

The oil from the Embar is practically without exception black and heavy after short weathering. Most of it is asphaltic, although there are exceptions. Because of the asphalt base, sulphur content, and low gravity, its market value is a good deal below that of other Wyoming oils. There is some evidence on hand to show that this disparity in gravity between the Embar oil and that from the higher horizons does not exist in the oil as it comes fresh from the well. Some of the wells of the Lander field that were tested in 1920 yielded oil so rich in dissolved gas that they gave phenominally high Baume readings. This suggests the desirability of methods of handling that will bring the value of the black oil closer to that of the lighter colored oils, now considered so much more valuable.

TRIASSIC

Chugwater formation.—The Chugwater formation, which lies immediately above the Embar, yields commercial amounts of oil and gas in the Hamilton dome of the Big Horn basin and in the Lander field in Fremont county. Besides these localities where large amounts of oil are obtained, seepages that have been noted in various parts of central Wyoming emphasize the necessity of recognizing the Chugwater as one of the oil-bearing horizons of the state.

In no place where the formation has been studied does it

appear to contain the types of rocks in which it is believed oil may originate. No organic shales are present, and such limestones as belong to the formation are apparently chemical precipitates barren of fossilized organic matter. Accordingly the source of most of the oil found in the Chugwater is presumably the Embar formation, and the Chugwater is valuable merely as a reservoir bed. Plainly, its potentialities might justly be considered nullified in regions where the underlying Embar is barren of oil.

The Chugwater is one of the most conspicuous of the western formations, composed of brightly colored, red, cliff-forming sandstones with intermediate shales of various shades of red and yellow, and, near the top of the formation, beds of gypsum in white cliffs which stand out strongly against the red background of the remainder of the formation. The thickness probably ranges from 500 feet in the Hartville region of southeastern Wyoming, where the formation equivalent to part of the Chugwater is called the Spearfish, to more than 2,000 feet in the neighborhood of the Big Horn mountains, where the red beds mapped as Chugwater include Permian and perhaps older rocks equivalent to a large part of the Embar, though the name was originally intended to cover only the Triassic red beds.

The oil of the Chugwater is commonly very similar to that of the Embar, being dark brown in color, asphaltic, and heavy. However, where both Chugwater and Embar are productive in a field, the Chugwater oil is, as a rule, somewhat lighter than that from the older formation. This difference has been consistently ascribed to the refining action from filtration exerted on the oil as it migrated upward from the Embar or lower beds where it must have had its genesis.

It should be emphasized that where oil is found in the Chugwater the possibilities of the Embar should also be tested, provided the depth of drilling which such testing would require is not prohibitive.

JURASSIC

Sundance formation.—The Sundance formation rests on the Spearfish beds in eastern Wyoming, on equivalent beds of the Chugwater in central Wyoming, and probably is represented in

extreme western Wyoming by the Twin Creek formation. Although it is not known to carry oil in commercial amount in any part of Wyoming, its position in contact with the Chugwater, which is known to contain valuable oil pools in parts of central Wyoming, indicates that there is a chance of its getting oil by upward migration from the underlying formations, if, indeed, petroleum is not indigenous to the formation itself in some localities.

The possibility of commercial oil yield from beds in the Sundance is brought out by the presence of oil seeps in several localities in central Wyoming. Most pronounced of these seepages are those in the Powder river field of Natrona county, better known to the oil men as the Tisdale district. The composition of the formation in central Wyoming suggests the possibility that the oil found in it is indigenous rather than that it reached the seepages by migration from overlying or underlying beds. It is composed essentially of about 300 feet of green marine shales with very fossiliferous thin interbedded limestones. In this region it lacks heavy sandstones that might serve as reservoir beds for any large amount of oil which might be formed, and therefore cannot be considered to hold great promise of large yields. In its type locality in northeastern Wyoming the Sundance contains a number of very massive sandstones which appear admirably suited to serve as reservoir beds, but in this part of the state the fossiliferous limestones are absent. In any event, oil has not been recorded from the Sundance either in extreme eastern or western Wyoming.

It appears that the Sundance cannot be considered a particularly promising horizon in any part of Wyoming. In the central portion, where there is evidence that oil is present in it, porous beds to serve as reservoirs are lacking. In other districts where such porous beds are present there is no evidence of indigenous oil. The logical conclusion is that the Sundance should not be made the objective of drilling operations, that is, a hole should not be started with the prime object of reaching the Sundance beds, but should be designed either to pass through them to the Chugwater and Embar horizons, or to stop short in higher oil-bearing horizons. At the same time the pos-

sibility of oil in the Sundance should be recognized, and showings of oil in this formation should be carefully recorded and studied, for they not only indicate the possibility of oil pools in the Sundance beds but also what seems to be an even better chance—that the oil may have accumulated in overlying porous strata of the Morrison formation.

CRETACEOUS

Morrison formation.—The Morrison formation has presented ample proof that it has oil-yielding potentialities. In the Big Horn basin phenomenal gas yields are ascribed to it. Ziegler[6] ascribes the gas in the Byron field to this formation, and if his correlations are correct, the Morrison must be credited with the largest gas wells in Wyoming. Recently deep driling in the Grass Creek field has encountered oil in quantity in a sand which almost certainly belongs to the Morrison. Seepages of oil have been reported from the Morrison on the flanks of Oil mountain in central Wyoming, and from the Tisdale (Powder River) field referred to in the description of the Sundance formation.

The oil and gas of the Morrison are probably not indigenous to it, but rather come from the marine shales and limestones of the underlying Sundance formation, or from deeper beds. This conclusion is strengthened by the association of oil showings in both formations in the Tisdale field and along Oil mountain, indicating that unless oil is present in the lower formation it will be absent in the upper one. Furthermore, in eastern Wyoming, where the character of the Sundance appears unfavorable for the formation of oil, no traces of oil or gas have been reported from the Morrison.

The Morrison has been traced from the Colorado line to the Montana line, and is present throughout eastern and central Wyoming. It has been correlated with the Beckwith of western Wyoming, although the formations have not actually been traced into each other. Measured sections range in thickness from 40 to 300 feet, with about 150 feet as a fair average. They

[6]Ziegler, Victor, The Byron oil and gas field: Wyoming Geol. Survey Bull. 14, 1917.

are composed of red, green and gray shales and lenticular sandstones, all of freshwater origin.

The Morrison (?) oil from the Grass Creek field, which is the only field of Wyoming where there is commercial production from this formation, is reported to be dark brown to black in color, but of good quality, high in specific gravity, and of paraffin base.

The same general rule for prospecting should be applied to both the Sundance and the Morrison, although the Morrison is considered much more likely to repay the prospector than is the older formation. The rule is, in brief, that in wildcat areas these formations should not be selected as the principal objective. The drilling operations should be designed primarily to test either the beds above the Morrison, or the Chugwater and Embar beds at greater depth.

LOWER AND UPPER CRETACEOUS

Dakota, Lakota and Cloverly.—The correlation and differentiation of the three units mentioned is so doubtfully made and so poorly established in Wyoming that, for the purpose of this paper, they can best be considered together. In places the Cloverly, as described in the Government bulletins, probably includes both Dakota and Lakota. In other places a formation is referred to as the Dakota which may in fact be the equivalent of the Lakota, or possibly not either the Dakota or the Lakota. In any event, there is in Wyoming a persistent zone of heavy sandstones, conglomerates and intermediate shales that occupy the interval between the Morrison below and the basal shales of the Colorado group above.

The oil-yielding potentialities of this zone are now becoming well recognized, although for many years the possibility of appreciable yield from this horizon, except in certain few favored localities, was scoffed at. The Greybull sand, one of the standbys of the northern part of the Big Horn basin, belongs to this group. In eastern Wyoming the Mule creek and much of the Lance creek production undoubtedly comes from this zone. In the Spring Valley and Labarge districts of western Wyoming a small production is credited to the Bear River —equivalent to at least a part of the group. Seepages of oil

and showings in wells from this zone are so distributed through the state that it has become quite evident that there is always at least a possibility of production, and in some districts it is of marked promise.

The oil contained in these beds is not believed to originate in them, but rather to have moved into them either from the overlying black shales of the basal Colorado, or from the Sundance or possibly deeper horizons. Although, in a few localities, there are dark shales and coals with abundant organic matter interbedded with the sandstones, these appear to be without exception of freshwater origin, and quite different from the dark shales commonly associated with oil formations. On the other hand, the overlying Thermopolis almost everywhere throughout central and eastern Wyoming contains oil in at least small quantity.

The thickness of the beds intermediate between the Morrison and the Colorado shales ranges from practically nothing to 350 feet or more in the eastern part of the state. If the Bear River belongs to this group of formations its thickness to the west increases to more than 1,000 feet. There is evidence that in places erosion has entirely removed the group, but a very fair degree of confidence that it will be encountered almost anywhere in Wyoming, where younger formations occupy the surface of the ground and where driling is carried deep enough, is quite justifiable.

The oil from the Cloverly, Dakota and Lakota is characteristically light green in color, high in the Baume scale of gravity, rich in gasoline and kerosene, and of paraffin base.

UPPER CRETACEOUS

COLORADO GROUP

Thermopolis (basal) Graneros (basal) Aspen.—The zone represented by these three formations is defined by the Dakota sandstone below (where present) and the Mowry shale or its equivalent above. If the correlations that have been published are correct, the zone is productive over a large part of the state. In Big Horn basin several fields get at least a part of their production from what is known as the Muddy sand in the

Thermopolis shale. The oil in the little field at Upton, Crook county, comes from the basal portion of the Graneros shale, which Hancock tentatively correlates with the Thermopolis. Seepages have been found in the Newcastle sand, correlated with the Muddy by Hancock, in a number of places along the western front of the Black Hills, and the New Osage field obtains its oil from this bed. In the Rock Creek field of the Laramie basin deep drilling has shown that a sand in approximately the position of the Muddy in the Thermopolis shale is oil-bearing. In western Wyoming the Aspen shale, which is believed to represent the Thermopolis and the Mowry combined (although it may represent but one of these) yields some oil.

Oil in the Thermopolis probably originated very close to where it is found. Probably much of the oil in the underlying Dakota, Lakota and Cloverly beds also originated in the basal Colorado shales. They are everywhere very dark in color, ranging from dark blue-gray to black. They are marine in origin, and in places are quite fossiliferous. It seems probable that they carry quite a voluminous microscopic fauna. In any event, the muds from which they were formed were replete with organic matter, as is evidenced by the somber color.

The great weakness of the zone, as a prospective yielder of oil, is the absence of sandstones or other porous beds adequate to carry the oil in sufficient concentration to make drilling operations profitable. In the Upton and New Osage fields the oil is contained in a sandy shale which rarely has enough sand to justify calling it a sandstone, although it is considerably more sandy, and therefore presumably more permeable than the enveloping shale.

This basal member of the Colorado shales, underlying the Mowry, is believed to be present almost everywhere in Wyoming where erosion has not degraded sufficiently to remove it, and its presence not only justifies drilling holes of depth adequate to test it but also encourages the belief that much oil will eventually be found in the underlying sands of the Dakota, Lakota, and other Cretaceous beds.

The Thermopolis may attain a thickness of 800 feet or more,

as is evidenced by sections measured in Big Horn basin, but it more commonly is less than 400 feet thick. It appears to thin from north to south, but no description of its source, thickness and extent, has ever been made available.

Mowry shale.—The Mowry shale immediately overlies the Thermopolis shale in Big Horn basin, and elsewhere in central Wyoming there is also a considerable thickness of dark to black shales between this formation and the Dakota-Lakota-Cloverly beds. In the Black Hills region to the east, beds lithologically indistinguishable from the Mowry of the Big Horns overlie the basal Granerous shale. In western Wyoming the Aspen formation bears the same relation to the overlying Frontier sandstones that the Mowry does, so they appear to be equivalent.

The Mowry yields oil in commercial volume in Big Horn basin. A little production was obtained from it in the Newcastle region of eastern Wyoming. The Aspen shale is one of the most dependable horizons in the Spring Valley field of Uinta county, and Schultz[7] believes that the oil found in the Wasatch beds in the Labarge field probably came from the Aspen.

Like the Thermopolis, the principal weakness of the Mowry and its equivalent appears to be the lack of reservoir rocks. In Big Horn basin it contains two good reservoir sands, but in most localities it seems probable that oil produced from it will come, for the most part, from joint planes, and will not be in great volume. However, there is every reason to believe that oil originates in these shales, whether or not it accumulates in them in commercial quantity. Almost any random sample will yield traces of oil when subjected to destructive distillation, and some oil can frequently be obtained when the shale is subjected to the action of solvents such as chloroform or carbon tetrachloride.

The character of the Mowry is remarkably constant, and is so characteristic that it is one of the most useful of the Wyoming formations for carrying correlation. It is light gray

[7]Schultz, A. R., The Labarge oil field, central Uinta county, Wyoming: U. S. Geol. Survey, Bull. 340, pp. 367-371.

to almost white when weathered, dark gray to blackish when fresh, fissile to blocky in cleavage, hard, and resistant to weathering. Everywhere it carries scattered fish scales. It is siliceous, although this silica is not everywhere present as sand grains. The thickness of the Mowry shale varies quite abruptly in some localities, increasing or decreasing as much as 25 or 30 per cent in a few miles. It ranges from more than 300 feet in the Powder River (Tisdale) district to not more than 50 feet in some places near the east line of the state. If the entire Aspen is equivalent to the Mowry, it may be said to thicken to 1,500 or 2,000 feet in the western part of the state. In any event, whether all or only a portion of the Aspen is the equivalent of the Mowry, it is undoubtedly thicker in western than in eastern Wyoming.

The oil of the Mowry is characteristically of high grade, of paraffin base, light green color, and high Baume gravity. The bituminous nature of the shale justifies a belief that it will probably yield oil in commercial amount wherever it is associated with porous reservoir beds and the underground water conditions are favorable. However, competent sands are so scarce in the Mowry shale that, unless nearby outcrops show the presence of such beds, the probability of a wildcat yielding an important amount of oil from this formation is slight, and it should not be made the objective of a test. Rather the test should either be stopped short, in the overlying Frontier formation, or should be designed to test the underlying Thermopolis and Cloverly sands.

Frontier formation.—The Frontier formation is probably the best known of the Wyoming oil-yielding horizons. Certainly it has yielded much more oil than any of the others. It is the "big pay" of the Salt Creek and Big Muddy fields, premier producers of Wyoming, and has also contributed to the output of fields from Elk Basin on the Montana line to Rock Creek near the Colorado line, and from the Osage district in the easternmost range of counties to the Spring Valley and Labarge districts in the southwest corner of the state. There are almost no districts, where the Frontier is present, where it has not yielded at least a showing of oil, either in

wells drilled through it, or as seepages at the outcrop of the formation.

The Frontier lies immediately above the Mowry shale, throughout central and southwestern Wyoming. In the eastern part of the state its horizon is not definitely established, although a rather thin sandstone, a little above the Greenhorn limestone, is by many tentatively correlated with it, and it would therefore be separated from the Mowry in this district by several hundred feet belonging to the Greenhorn and the upper part of the Graneros formation. The importance of the horizon as a reservoir bed throughout central and north-central Wyoming makes it appear particularly unfortunate that the correlation with what appear to be corresponding beds in eastern Wyoming has not been more definitely established.

The following description of the formation, taken from Hares[8], is applicable to the central Wyoming region and much of Big Horn basin.

> The Mowry shale is overlain by shale and sandstone that are referred to the Frontier formation, of Upper Cretaceous age. The sandstones, of which there are three distinct divisions corresponding in ascending order to the Peay, an intermediate sand, and the Wall Creek, are of medium to fine grain, gray, somewhat massively bedded, and from 20 to 200 feet thick. The formation attains a maximum thickness of 1,000 feet. The intervening shale, which makes up more than half of the formation, is dark and sandy. The lowest sandstone member, corresponding to the Peay, is persistent and characterized by large brown concretions, especially in the Emigrant Gap and Oil mountain anticlines and the Pine dome. The middle sandstone is commonly characterized by small black chert pebbles about the size of peas, which usually distinguish it from the other two sandstones, though in a few places the Wall Creek contains similar pebbles. The upper or Wall Creek sand is the main productive oil sand in the Salt Creek field, 25 miles northeast of the North Casper Creek anticline, but the Peay and Torchlight are important producing sands in the Big Horn basin. The Wall Creek sandstone may correspond to the Torchlight, as shown by Hintze, for it is stratigraphically at about the same position.

The Frontier of the western part of the state is much thicker than it is in central Wyoming, aggregating 2,000-3,000 feet as against 2,000 feet in central Wyoming, and presumably much less (dependent upon how much of the Greenhorn and

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[8]Hares, C. J., Anticlines in central Wyoming: U. S. Geol. Survey, Bull. 641, p. 246, 1916.

Graneros can properly be correlated with it) in extreme eastern Wyoming. The character throughout is the same—an alternation of marine sandstones and shales, such as are described in the quotation by Hares, given above.

Oil from this formation is without exception of paraffin base, high gasoline content, light green to brown in color, low in sulphur, and in all respects a good refining oil.

Wherever the Frontier is believed to be present, on good anticlinal structure, below 200 feet or more of cover, and within drilling depth of the surface, it is justifiable to drill for it. None of the Wyoming oil-bearing horizons may be characterized as reliable, but this formation is probably the most consistently oil-bearing of the entire series.

Niobrara shale.—So far as is positively known, oil in commercial amount has been found in the Niobrara shale, or beds that are its stratigraphic equivalent, in but one or two localities. It is possible that the production of the Rangely field, in Rio Blanco county, Colorado, might correctly be said to come from beds equivalent to the Niobrara. In Wyoming the Hilliard shale of Uinta county, in the southwestern part of the state, includes beds that are probably the time equivalent of the Niobrara, but it has been impossible to prove whether or not the oil produced from the Hilliard comes from beds of this precise age. In the Salt Creek field of Natrona county the Niobrara has yielded notable amounts of oil, which are believed to have seeped up from the underlying Wall Creek sand of the Frontier formation.

The Niobrara in central and eastern Wyoming is separated from the underlying Frontier by the Carlile formation—black shales some 100 to 200 feet thick. It is believed to be present practically everywhere in Wyoming where the Colorado group is under cover, although in some places it absolutely cannot be differentiated by its lithology, and doubtfully by its fauna. In central and southern Wyoming it is a shale with minor amounts of limestone. The color is typically a creamy buff, but this grades to a dull gray which cannot be distinguished from that of the overlying Pierre shale. Practically everywhere the shale is limy, and in Colorado so much of the formation is limestone that it is used for making cement and lime.

Such very minor amounts of oil have come from the Niobrara that production from it is not to be expected, and when encountered is to be regarded more as an unusual and welcome gift than a merited discovery.

The oil that has been found in the Niobrara is of high grade, and, could it be found in appreciable amount, would be of great value.

MONTANA GROUP

Shannon sandstone.—The Shannon sandstone is a member of the Pierre shale, from 1,000 to 2,100 feet above the Frontier sandstone. It has yielded oil in commercial quantity in the old Shannon pool at the north end of the Salt Creek anticline, and has also manifested abundant indications of an oil content in the so-called Douglas field. Where it has been observed in other localities it is apparently barren.

The extent of this member of the Pierre shale has not been determined. In the Big Muddy field, southeast of Salt creek, it seems to be absent[9], but in the Douglas district a sandstone about 300 feet thick occupies at least approximately the same horizon as the Shannon of Salt creek, and in the old Powder River (Tisdale) field it is approximately 175 feet thick, corresponding roughly to the thickness in the Salt Creek district. Hancock[10] has tentatively correlated a bed 30-40 feet thick in the Lance Creek district with the Shannon, because of its position below the top of the Pierre shale. There is little doubt that the sandstone referred to in the Lance Creek district occupies the general horizon of the Shannon, although it will probably never be possible to establish a definite correlation.

The oil obtained from the Shannon in the Salt Creek district is light to dark green in color, of paraffin base, specific gravity about .909 (24° B.), with a very low content of gasoline, and even of kerosene. It is said to have properties which make it particularly desirable for the manufacture of lubricating oils.

In view of the uncertainty regarding the extent of the Shannon sandstone member, prospecting for oil in this bed car-

[9]Barnett, Victor H., U. S. Geol. Survey Bull. 581, p. 113, 1913.

[10]Hancock, E. T., The Lance Creek oil field, Wyo.; U. S. Geol. Survey Bull. 716-e, 1920.

ries more than the usual amount of risk, and should be undertaken only by operators who recognize the strong probability of failure—a probability that is made very strong by the apparent barrenness of the Shannon where it has been observed outside the Salt Creek district. However, there is a possibility for production, and strong companies will be quite justified in determinedly prospecting it.

Parkman sandstone.—Where the Pierre shale is subdivided into the Steele and Mesaverde formations the sandstones of the upper portion of the Pierre are thrown into the Mesaverde. The basal Mesaverde sandstone in the central Wyoming region is known as the Parkman. In eastern Wyoming the Parkman may be the heavy basal sandstone of the Fox Hills, although this relation has not been established.

The Parkman has not been proved to contain oil or even gas in commercial quantity in Wyoming. However, its character and its relation to the underlying marine shales of the Pierre or Steele demand that it be recognized as a potential oil-yielding formation, and it will not be in the least surprising if it proves to contain important bodies of oil where it is under several hundred feet of cover and arched by anticlinal folding. The oil in the Shannon demonstrates that the Pierre must be considered a source of oil, and if so, any sandstone in contact with it is likely to receive some of the oil formed, even though the shales immediately underlying the sandstone may themselvs be barren.

The Parkman is present throughout central Wyoming, having been noted as far southeast as the Douglas field of Converse county. The type locality is the station of Parkman in Sheridan county, but a short distance south of the Montana line, so it is present throughout Big Horn basin. It has been traced far north into Montana, where it is approximately at the base of the Judith River formation.

The recorded thickness of this sandstone ranges from 150 feet in the Douglas field to almost 500 feet in the Salt Creek field. It commonly has three divisions—a basal sandstone, an intermediate division of thin sandstones, shales, and beds of coal, and an upper division of sandstone, although in the type locality the upper sandstone is apparently missing.

Teapot sandstone.—The Teapot sandstone forms the top of the Mesaverde formation in central Wyoming, where it is from 90 to 200 fet thick, and is separated from the underlying Parkman by about 700 feet of shale. In south-central Wyoming, a heavy sandstone in the upper part of the Mesaverde has been called Teapot by many of the geologists who have worked the region to determine its oil possibilities, but definite correlation of this bed with the Teapot of central Wyoming has never been announced. Similarly, lithology and general relations make it highly probable that some one of the Fox Hills sandstones in eastern Wyoming corresponds to the Teapot, but definite correlation will be extremely difficult, if not absolutely impossible.

The Teapot is classified by Hares[11] as "the highest Cretaceous sand in which oil was observed" in the central Wyoming district. Along the east flank of the Rattlesnake mountains it is saturated with oil in one or two localities. Elsewhere it has not been proved to contain oil, and in fact its prospects to have such an oil content do not appear as good as do those of the Parkman since the underlying shales of the Mseaverde are dominantly of freshwater origin and appear less likely to contain organisms from which oil may form than do the shales of the Steele or lower part of the Pierre.

Until the barrenness of both Teapot and Parkman have been much more thoroughly established than they are now, it will be quite justifiable to drill structures in which they are the only prospective oil-yielding horizons within reasonable drilling depth, for if it can be demonstrated that they may be considered important oil-yielding beds, much territory that is now looked upon as of little prospective value by Woming oil men will be added to the potential oil fields of the state. However, the statements concerning prospecting the Shannon sandstone apply also to Parkman and Teapot.

If oil in commercial amount is found in the Mesaverde it will probably be a light oil of paraffin base, comparable in value to the oil from the Frontier.

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[11]Hares, C. J., loc. cit., pp. 246-247.

TERTIARY FORMATIONS

EOCENE

Wind River and Wasatch formations.—Although the Wind River and Wasatch have not been actually proved to be exactly contemporaneous, as areas where neither formation is present prevent their being traced into each other laterally, their general similarity in character justifies their being considered together when only the prospects of oil production from them are involved.

These formations must be included in any full discussion of the oil-bearing beds of Wyoming, for not only have oil seepages been observed in them, but also oil from the Wasatch has actually been produced and marketed. The Wind River formation on the west flank of the Dutton anticline, Ts. 33 and 34 N., R. 90 E., is reported by Knight[12] to include some beds containing oil. It is also reported[13] to show traces of oil south of the Owl Creek mountains in T. 39 N., R. 92 W. The Wasatch formation has even more pronounced indications of oil content than has the Wind River. In fact, some oil has been produced from it in the small shallow fields of southwestern Wyoming. However the oil is not believed to be indigenous to the Wasatch, but rather to rise from the underlying Beckwith and Aspen formations along fault planes[14]. This conclusion is strengthened by the nature of the Wasatch beds, and the Wind River is so similar that there appears little doubt that the oil found in it actually originated in some other formation and migrated to its present position, either along fault planes, or along a plane of unconformity.

Both of the formations mentioned are of fresh water origin and made up, principally, of beds or red, gray, and yellow sandstone, and clays with the same color range. Bituminous clays, shales, or limestones that might be "mother beds" of oil appear to be practically absent. Some thin layers of coal occur, but they are in most cases thin, of small extent and not accom-

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[12]Knight, W. C., Wyoming Univ. School of Mines, Petroleum Ser., Bull. 4, p. 16.

[13] Hares, C. J., loc. cit., p. 247.

[14]Schultz, Alfred R., loc. cit., p. 371,

panied by appreciable thickness of shales carrying organic matter.

It must be recognized that these formations may yield oil, but this probability is limited to areas where strong faulting occurs, or where the Tertiary beds lie unconformably upon the bituminous layers or some oil-yielding formation. Prospecting in areas where these conditions are not known to occur, and where the thickness of Tertiary beds is such that the sands of the Mesaverde cannot be reached is difficult to justify.

Green River formation.—The Green River formation is noted particularly for its shales that yield oil by destructive distillation, and has not been regarded as a potential reservoir of liquid petroleum. However, it cannot be disregarded, for experiment has shown oil may be generated from the shales by temperatures and pressures such as are possible in nature: free oil has been observed in small sandy lenses in the shales, and the upper part of the formation has an abundance of sandstone which should be suitable for oil-retaining beds.

Prospects for oil in this formation are probably largely limited to areas that have been deformed, or that have unquestionably been subjected to stress more intense than appears to have affected the greater part of the formation. In most ocalities it lies almost flat, or at best gently flexed, nor is there evidence that it was covered by any great overburden of younger formations that would produce high pressures and temperatures. However the possibility of production from regions where deformation has taken place should not be overlooked.

The exposed Green River formation in Wyoming lies, for the most part, in Sweetwater county, although it is presumably present beneath the surface in some of the adjacent counties to the west.

OLIGOCENE

White River formation.—The White River formation of Oligocene age is the youngest of the Wyoming formations in which oil has been found. Commercial production from this county, where gas, numerous "showings" of oil, and actual

production of a few barrels have resulted from the drilling of a few shallow wells.

There is apparently no likelihood that any oil the White River formation may contain originated in the formation itself. Like the Wind River and Wasatch formations, an oil content is believed to depend upon conditions that have favored the migration of the petroleum from subjacent beds, and prospects of oil in this formation are necessarily limited to areas where these conditions favorable for migration are believed to hold.

The White River formation spreads over great areas in central and eastern Wyoming, as well as in neighboring states and is described by Hares[15] as

composed essentially of loosely cemented, light-colored fine and coarse sand, arkose, and conglomerate. Volcanic material, in the form of pebbles and single grains is present throughout the formation. Red color is generally absent, but light green and buff are plentiful and even white rocks are not uncommon. The White River is nearly flat lying and rests unconformably on all formations from the pre-Cambrian granite to the Steele shale and the Wind River.

Oil from the White River formation would naturally vary in character, depending upon its original source and the history of its migration. If it originally came from the Cretaceous measures it would probably be light green, high Baume gravity, and of paraffin base, although contact with certain types of water during its migration might well alter its character, rendering it heavier, darker in color, and in general reducing its value. On the other hand, if the oil moved through dry, porous beds for some distance before reaching its final resting place it would probably be lighter in color and specific gravity than it was when it started its migration, due to the filtering and refining action of the porous material. If the oil came originally from the Madison or Embar, it would probably be heavy, dark in color, of asphaltic base, with a considerable sulphur content. During migration it might be acted upon so that it would reach the White River beds either lighter or heavier than when it started, with the probabilities favoring the former.

[15]Hares, C. J., loc. cit., p. 247.

Prospecting in areas covered by the White River formation is justifiable only where there is reason to believe that the underlying Mesaverde (or equivalent, possibly oil-yielding beds) are within drilling depth, where there is pronounced folding or faulting, or where there is reason to believe the White River resst unconformably on the edges of one of the prolific, underlying oil-bearing beds.

NEED OF DETAILED STUDY OF STRATIGRAPHY

The preceding summary presents the salient facts known or inferred about the oil yielding or prospectively oil-bearing horizons of Wyoming. It is immediatey apparent that far too little is known to permit the oil resources of the state to be developed to their full extent, without a tremendous waste of money spent in drilling barren structures or abandonment of holes at too shallow a depth. There are doubtless many areas in the state that are oil-bearing, which have never been prospected. On the other hand, many areas have been and will be prospected with enthusiastic intensity without repaying the cost of drilling. A part of this is unavoidable, but much of the waste, and the neglect of promising territory, can be obviated if the available knowledge is brought to light and put to work.

Of maximum importance for the development of the oil fields, is as precise a knowledge of the stratigraphy of the entire state as present methods of geological field work make possible. The thickness, character, and extent of the formations—both oil-bearing and non-oil-bearing—must be ascertained. The manner in which thickness and composition vary must be comprehended with such thoroughness that even where a formation, if present, is concealed under a heavy burden of younger beds, its presence or absence may be inferred, and its thickness and character known within small limits of error. Of particular importance is an accurate knowledge of the character and thickness of the Tertiary formation, which cover about 30 per cent of the State, for prospecting has heretofore been almost restricted to areas where Mesozoic and Paleozoic rocks appear at the surface. This restriction is quite justified by the present lack of knowledge of the thickness of the Tertiary beds, and of the nature of the formations that un-

derlie them. Prospectors are confronted with the possibility that they may drill through 3000 feet of Tertiary rocks and still be an equal distance above the possibly oil-yielding beds of the Cretaceous formations.

To obtain this desired knowledge of the stratigraphy of Wyoming will involve studies of the origins of the various formations. The sources of the material, type of deposition, and the history of the laying down of the formation—whether continuous or interrupted, rapid or slow—all must be understood. The extent of the formation in many instances cannot be learned by a study of the beds in Wyoming alone. The positions of the shore lines of the sea or lake in which the subaqueous beds were laid down should be learned as should also the posiiton of the outer "feather edge" of the formation. Where the formations are of sub-aerial origin the general outlines of the basins in which they were formed or of the paleogeographic features that determined their extent and character should be located, for each of these factors has a bearing on the possibility of oil production.

Inseparable from a study of the stratigraphy is the study of the geologic history. This will summarize knowledge of the changes that took place in a formation both during and subsequent to its formation. It will show definitely the position of the most significant unconformities and if properly carried out, will permit fairly accurate estimates of the amount of cutting down during the time of degradation, of how the material that was removed during the periods of erosion, was transported, and the probable character and location of the resulting formations. It will also reveal the periods of strong deformation, which bear directly upon the location and extent of the oil pools.

The potential value of an untested area cannot be grasped accurately even with the data made available by the above studies, unless the nature and significance of the geologic structure is understood. The oil-yielding beds of Wyoming have been affected by intermittent deformations that range from Madison time to the Pleistocene. There is ample evidence that the last deformation affecting parts of the state was

post-glacial, and the statements often heard that the Tertiary and Quaternary beds are "flat" and "without structure" are absolutely unjustifiable. Synclinal or anticlinal folds in these beds are in places sharply pronounced, and the beds are rarely formation has been limited to the Douglas field of Converse absolutely flat, or even purely monoclinal. It is necessary to learn how much of the apparent structure is in fact due to depositional dip, and the relation the true folding bears to more pronounced folds in underlying older rocks—if indeed, any relation whatsoever can be established.

It will be noted that the program very briefly sketched does not call for the detailed study of the different oil-bearing formations, to determine the intimate details of their composition, texture, porosity, tendency to form solution cavities, joint openings, or other types of openings which would make them serviceable as reservoir beds. Such detailed studies are desirable—in fact are badly needed—but at best apply to restricted areas. Of first importance is a grasp of the factors that will affect large areas. These broad studies will inevitably make available much of the nedeed detailed knowledge, but even so the careful working out of the characters of the various oil-bearing beds forms a separate problem.

Broad studies, such as this one of the stratigraphy and geologic history of the Wyoming formations, are outside the scope covered by the geological investigations of most oil companies. In fact, only one or two in the United States are equipped to carry out such a study, as it would demand for its successful completion the services of skilled stratigraphers and physiographers, preferably with years of acquaintance with the formations to be studied, supplemented by paleonotologists and paleobotanists capable of identifying correctly faunas and floras ranging all the way from Cambrian to latest Tertiary. In short, it seems the type of investigation that can best be carried on by the U. S. Geological Survey and present plans call for its inauguration during the summer of 1921.

THE WEST COLUMBIA OIL FIELD, BRAZORIA COUNTY, TEXAS

By Donald C. Barton

INTRODUCTION

The West Columbia oil field is the youngest of the first rank salt dome oil fields of the Texas-Louisiana coastal region, and at present is the most productive of these fields. It is in the central western part of Brazoria county, Texas, just west of Brazos river. It is 50 miles southwest of Houston and twelve miles southeast of Damon Mound.

HISTORY OF THE FIELD

Kaiser's Mound, as West Columbia was known in the early days, was one of the many mounds to which attention was drawn in 1901 by the bringing in of the enormous gushers on the Spindletop mound. Before the end of the year the Equitable Mining Company had put down a test well at West Columbia, a shallow 680 foot well, on the low hill on the Arnold tract on the southeast edge of the dome. The second well was put down by the same company in 1904 not far from the first. It was a shallow 498 foot well but encountered a heavy gas pressure at 480 feet. The well blew out and then flowed a few barrels of heavy oil for more than a year. Sinclair and Crosbie then drilled a 1200 foot well, also on the Arnold tract. It had some fair showing of oil but did not produce. In the next few years numerous shallow wells were put down. Out of several shallow tests the Markham Fuel Company got a small well at 380 feet on Lot No. 16 of the Hogg subdivision. It had an initial production of 50 barrels of heavy oil and produced altogether about 1000 barrels. It was finally abandoned on account of water troubles and the low price of oil. The Brazos Oil Company drilled a water well to the same

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depth and very close to the Markham Fuel Company's producer. The Brazos Oil Company then moved north of what is now the Hyde subdivision and struck salt at around 863 feet.

Between 1907 and 1910, the West Columbia Oil Company and the Palacios Oil Company drilled numerous shallow wells west

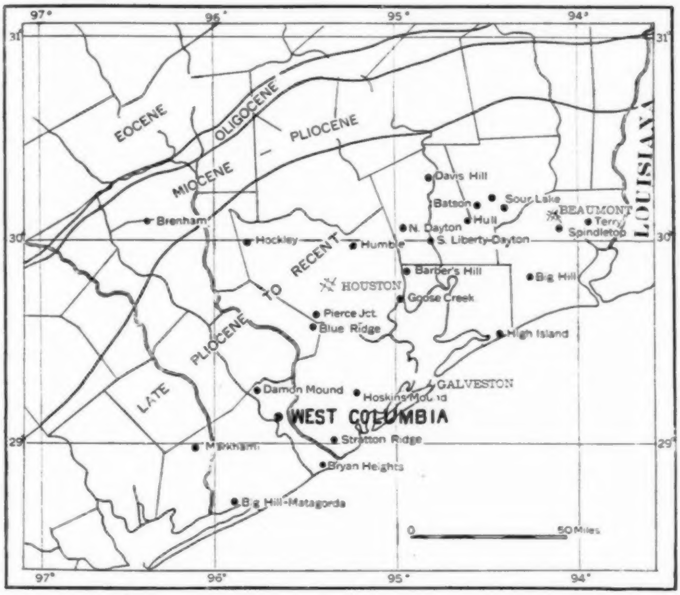

Fig. 1. Sketch map showing the location of West Columbia and its position with reference to other salt domes.

of the Arnold tract. The first well of the West Columbia Oil Company and the second well of the Palacios Oil Company went into the salt at about 800 to 900 feet. These wells were located in the central depression. The rest of the wells of these companies were drilled on the hill on the southwest side of the central depression. Of these wells, the Palacios Oil Company's No. 3, located on top of the hill, oozed oil from 496 feet for years. The West Columbia Oil Company's No. 2 struck a 12½ foot pay in rock at 480 feet, blew out and went to gassing by heads. When the hole was cleaned out, oil shot 25 feet over

the 80 foot derrick, but the oil was soon drowned out by water and the well was abandoned. Well No. 3, drilled by the paraffin dirt bed on the west side of the hill, went into heaving shale at 900 feet, and No. 4 was abandoned at 662 feet in a sand which was as fine as flour and flowed a highly mineralized water.

In October, 1913, the Producers Oil Company started a drilling campaign in the west quadrant of the dome. Most of the wells were deep tests for those days, going to over 2000 feet. Of these wells the first is said to have had 10 feet of pay at a depth of 2190 feet with much gas, but it was not a producer. Nos. 2, 3, 4, and 5 were abandoned on account of heaving shale. Nos. 6 and 6A were both junked after drilling to a depth of about 1500 to 1600 feet. A 3200 foot test which had some gas and a showing of oil was finally drilled west of the road. At the time the Abrams well came in, the Texas Company was moving in a heavy California rig outfit in preparation for an attempt to make a deeper test in this heaving shale area.

In September 1917, the Tyndall Wyoming Oil and Development Company brought in the first producer in the deep sands of the southeast field. It did not go deep enough to strike the main pay sands but flowed and pumped a small amount of 21°B. oil from a higher sand. Late in the year the company brought in a 200 barrel well on the adjacent block, No. 17, of the Hogg subdivision. Following the completion of this well, the larger companies began to take an interest in the field. The Texas Company started drilling in the Arnold tract in the summer of 1918 and during the first week in January, 1919, brought in its Arnold No. 2, which made 6500 barrels through a 1½ inch choker and was estimated to have had a potential daily capacity of 20,000 barrels. A few weeks later, the Humble Oil and Refining Company brought in its Giraud No. 1, which was reported to have had an initial production of between 7,000 to 12,000 barrels daily.

Following the completion of these wells, the field developed rapidly. By the end of 1919 it was apparently delimited by dry holes on the south, north and west, to an area of about 60 acres. By the late spring of 1920, the maximum production of this area was past. Although every now and then big wells

were still brought in, the new production was not sufficient to offset the decreasing production of the older wells and the field was apparently on the decline.

On July 20, 1920, the Texas Company's Abrams No. 1, the so-called "Wonder Well of the Gulf Coast," came in on the north side of the dome, ¾ of a mile from production, with an initial production of between 25,000 and 30,000 barrels daily, of clean oil. The well came in unexpectedly, while the crew were drilling ahead with a Hughes bit in 250 feet of open hole. The drill stem was capped and a valve placed on the end of the casing. Up to the first week in September, the well continued to flow at approximately its initial rate. The production then dropped suddenly. The drill stem was uncapped and the well began to flow at the rate of 10,000 barrels daily. At the end of 76 days the well had produced 1,275,000 barrels of oil, with a value of $3,825,000.

Following the completion of the Abrams No. 1, there was a rush for acreage on the north side of the dome, but as the Abrams No. 1 was on the south edge of a solid block with the Texas Company's Hogg lease to the south, the nearest any of the other companies could get was the south edge of the Jackson subdivision, 1200 feet north of the Abrams No. 1. Here several companies brought in wells of moderate size. In the meantime, the Texas Company offset its Abrams well with Hogg No. 49, which came in with an initial production of 30,000 barrels.

Late in the summer following the completion of the Abrams well, the Gulf Production Company brought in its W. C. Hogg wells and extended the old field some 800 feet to the east, and also extended the old field 1000 feet to the northeast with its Masterson No. 1.

By December 1, the excitement engendered by the completion of the Abrams No. 1 died out completely. B. S. and water appeared in both the Abrams No. 1 and its offset and the production dropped off badly. The wells on the south edge of the Jackson subdivision have gone rapidly to water and the wells farther north and the Gulf Company's W. C. Hogg wells northeast of the dome have been failures.

PHYSIOGRAPHY

West Columbia lies within the almost featureless, late Pleistocene coastal plain which extends 60 to 80 miles back from the Gulf of Mexico and which is probably the equivalent of the Pensacola, Hammone and Port Hickey terraces of Matson to the east. Except for the scattered stream valleys and few salt dome mounds, this plain has no relief greater than 10 feet. West Columbia lies in an alternating wooded and

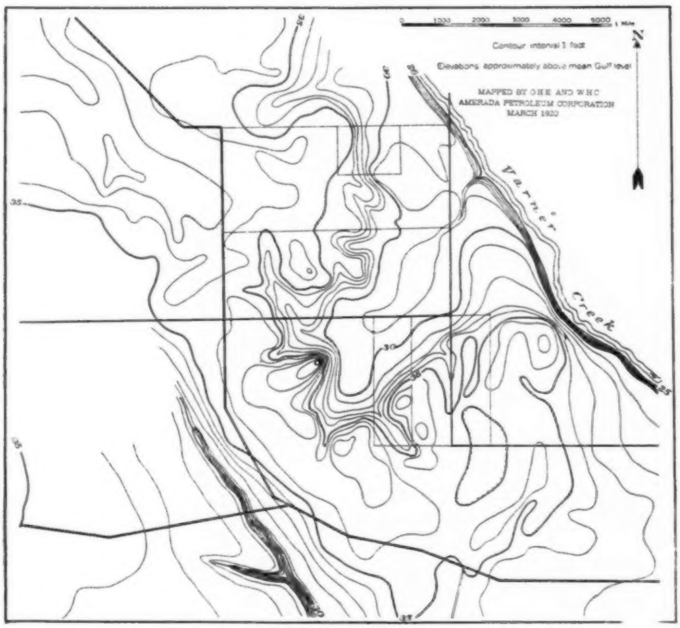

Fig. 2. Topographic map of West Columbia.

ner's creek, a small tributary of Brazos river, cuts across the open portion of this level prairie, between Saint Bernard and Brazos rivers. Although the latter is one of the larger rivers of this part of Texas, it does not have a marked valley bottom and has effected little noticeable erosion in this region. Var-

northeastern edge of the dome and has caused some local erosion.

The surface expression of a salt dome commonly is a circular or nearly circular mound rising above the general prairie level. The mound in many cases has a marked central depression. The West Columbia salt dome mound is a very faint one of the central depression type, which has been much obscured by erosion. The central marshy area which marks the general position of the central depression is separated from Varner creek by very slightly higher land, which is dry except during times of high water. This faint ridge may be taken as the northeast rim of the mound, but is more probably a faint natural levee of Varner creek. On the north the mound has been obscured by erosion, but on the west, south, and east, it can be made out rising gently from the surrounding prairie to an elevation of a few feet above the general level, and then sloping rather steeply to the central depression. The highest point, the crest of the hill on which is situated the Texas Company's camp, rises about 10 or 12 feet above the general level to the southeast of the dome, and 8 or 10 feet above the general level to the southwest, and 5 feet above the general level. The floor of the central depression lies 20 to 23 feet below the crest of the Texas Company camp hill and 18 to 20 feet below the crest of the southeastern rim.

On two sides of West Columbia there are marked prairie ridges. On the northwest a ridge runs northwestward toward Damon Mound. This ridge rises about 5 feet above the general level and is about 1½ miles wide. East of Varner creek there is a marked ridge running northeastward more or less in continuation of the northeast rim of the West Columbia salt dome mound. This ridge is broad and low with a width of 1½ miles and a height of 5 to 10 feet above the general prairie level. Ridges of this character are not uncommon in connection with the salt domes, the salt dome, in most cases, seeming to rise through the ridge. The ridges run for miles across country and are not limited to the immediate vicinity of a known salt dome. In a few cases they seem to connect salt domes. No wells have been drilled as yet in position to give a

good cross-section of such a ridge and it is not known whether they are significant of deepseated structural deformation, perhaps associated with the formation of the salt domes, or whether they are due, as Hager suggests, to settling of the sediments.

SURFACE GEOLOGY

The beds exposed at the surface in the general region of the West Columbia mounds are the clays and sandy clays of the Pleistocene Beaumont clay. The mound appears to have a somewhat more sandy soil than that of the surrounding territory but the difference is slight.

SUBSURFACE GEOLOGY

A salt dome consists typically of a plug or core of rock salt, a thimble-like cap of limestone, anhydrite, or gypsum mantling the salt core, and steep, quaquaversally dipping beds around the salt core. The latter is circular or elliptical in plan, with a diameter of about half a mile, as in the case of Anse la Butte, to three and one half by one and one half miles in the case of Stratton Ridge. The salt has nearly vertical sides and a relatively flat top. The flatness, however, is relative and there may be fairly steep slopes at the top of the salt. The cap may be hundreds of feet thick, or thin on top and sides, or it may be practically absent. The dip of the beds on the flanks of the dome varies in different domes and with the depth of the bed. In many cases it is around 1 in 2, but it is less for the shallower beds and probably greater near the edge of the salt.

The salt core at West Columbia is nearly circular in outline and has a diameter of 9500 feet. The top of the salt mass is relatively flat. Its highest elevation is 750 feet below sea level in the northeast, sloping to 825 feet below sea level at the south and west. On the east there is apparently some irregularity in the surface of the salt, as a well is reported not to have encountered solid rock salt 1250 feet below sea level but this was an old well and the salt may not have been recognized. The slope of the edge of the salt is high. Wells have not been drilled in position and depth to give the actual slope but in the northern edge of the southeast productive field, there is an inclina-

tion of more than 917 feet in 400 feet, or a slope of 65 degrees. On the northeast and northwest sides of the core the angle between the bottom of the wells now drilling which have not encountered salt and the depths of the top of the salt in the nearest salt wells is over 70 degrees. It is not improbable that the actual slope of the sides of the salt is nearly vertical. The thickness of the salt mass is not known, as no well has been drilled more than 600 feet into the salt. From the experience in the other Gulf Coast salt domes, where wells have been drilled 3000 feet in solid salt and abandoned still in the salt, it can safely be assumed that the salt mass is probably well over 3000 feet in thickness.

A gypsum-anhydrite cap is present at West Columbia but is not as well developed as on many of the domes. It is found on the north part of the dome with a thickness of about 100 to 150 feet. On the southern part of the dome, it seems to be absent. Deep on the east flank, the Chance salt well failed to find any cap immediately above the salt. It did, however, encounter 160 feet of "gyp" at a depth of about 1800 feet, which may or may not be a continuation of the cap.

Lithologically, the cap rock, as represented in the cores of the old Palacios Oil Company's No. 2, is mixed anhydrite and gypsum. The anhydrite is very fine, saccharine, bluish white in color and fairly massive, but shows a faint banding with a dip of 10 to 15 degrees. This structure is well shown in the core, pictured in Fig. 3, by the tendency of the gypsum to replace the anhydrite parallel to this banding. Anhydrite of this character with banding, or in some cases with banding only faintly developed, is one of the most common cap materials in salt domes but as the drillers fail to distinguish it from gypsum it is practicall always logged as "gyp." Very similar anhydrite has been seen by the writer from Palangana, Damon Mound, North Dayton, and Stratton Ridge.

The gypsum occurs in two forms, one as clear, allotriomorphic crystals of selenite up to several inches in diameter, the other as fine grained, micaceous selenite having very much the appearance of a fine grained mica-schist. As can be seen from Fig. 3, the gypsum is secondary and a replacement of the

anhydrite. In some cases, as in Fig. 3 right, the anhydrite seems to alter first to the fine grained micaceous selenite and the latter gradually alters to the large crystals of selenite. In this case, some of the contacts between the anhydrite and the fine grained selenite are fairly sharp but in others slightly indistinct. The contacts between this selenite and the large crystals of selenite are sharp. In other cases, the fine grained selenite is not found and there is a fairly sharp contact between the anhydrite and the large crystals of selenite. The

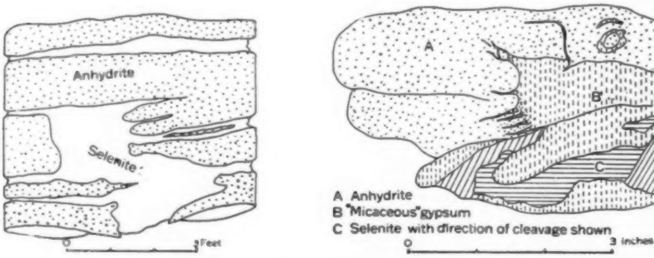

Fig. 3. Sketch drawings of specimens from West Columbia showing the relations of anhydrite, gypsum and selenite.

alteration of the anhydrite to the gypsum seemingly tends to take place parallel to the banding but it also follows cracks and fissures at an angle to the banding, and, as can be seen in Fig. 3, it may take place irregularly.

Above the cap rock, there are sediments which are probably flat-lying, although there is some possibility, if not probability that the lower beds may be somewhat faulted. The number of wells drilled on top of the dome, however, is not sufficient to allow a study of the structure of the super-cap beds. These beds consist of Pleistocene and perhaps older sands, gravels, and clays, and at least one thin limestone. What the age of the lower super-cap beds may be is not known. On the analogy of the German and other salt domes there is the expectibility that the lower supercap beds may belong stratigraphically several thousand feet below their present position.

On the flanks of the dome, the normal sediments of the Gulf Coastal Plain series, together with some beds of secondary

"rock", dip quaquaversally away from the central salt core at angles of 13 to 25 degrees at a depth of 3000 feet and 7 degrees at a depth of 1000 feet. In the zone immediately adjacent to the salt dips are probably much steeper and the beds much broken by faulting. It is practically impossible in this zone to make correlations which have enough probability to be of use.

Lithologically the sediments of the lateral beds, as reported by the drillers consist of sand, clay, gumbo, shale, heaving shale, rock and "gyp." The "gyp" is mostly gypsum, but may be anhydrite, limestone, or white shaly clay. The "rock" for the most part is sandstone but is in part gypsum, anhydrite (?), and limestone (?). Much of the true sandstone is locally cemented sand. It is a rule that there is more cementation of the sands on the flanks of a salt dome than is normal for the same sands off the dome. The same holds true of the super-salt beds. The shale is really a shaly clay, which progressed far enough in the change from clay to shale so that it does not absorb water quickly and become plastic. Gumbo is merely a stiff sticky clay. The heaving shale, as reported by drillers, is a somewhat abused term but is at least in part an impure Fuller's earth. It absorbs water readily and although it can be drilled through the heaving shale immediately fills up the hole as soon as the tools are withdrawn and according to the drillers even "heaves" up the hole for some distance. It is then impossible to get to the bottom again without redrilling through the heaving shale in the hole. On the west side of the dome there is much heaving shale. The Texas Company's Hogg (Kaiser) wells No. 1, 2, 3, 4, and 5 were abandoned in it on account of the difficulty of setting through it. Its greatest development was said to have been around 2200 feet, but it was found at practically all horizons from 900 feet down to 2500 feet. In the southeast field small beds of it are found but are not sufficient to impede drilling.

STRATIGRAPHY

Beaumont clay.—The uppermost five to six hundred feet of the section penetrated by the drill are sands and clays of the Beaumont clay, of Pleistocene age. The thickness of this for-

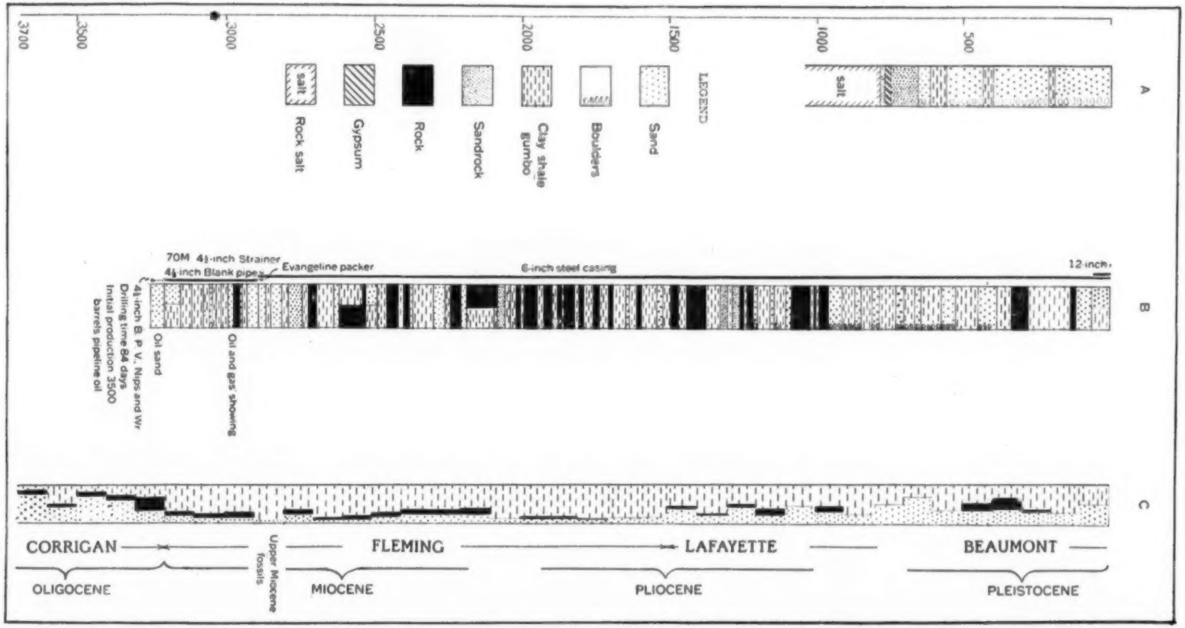

Plate I. Graphic logs of wells from the West Columbia field. A. Well from top of dome. B. Typical well from the southeast field. C. Composite log of four tests drilled well out on the southeast and south flanks of the dome (Sun Company's MacGregor No. 1, Crown Oil & Refining Company's Sealey No. 1, Lucky Jim Oil Company's Brown No. 1, and Gulf Prod. Company's Sweeney No. 1).

mation and the position of its base are difficult to determine. The appearance of heavy beds of sand, gravel, and rock, according to Dumble, are an indication of transition to the underlying formation. In the main area of the southeast field there is a heavy sand with "boulders" which appears between 500 and 600 feet. In a composite log of four of the deep wells farthest out from the salt (Plate I) the respective percentages of clay, "rock," and sand and the amount of "boulders" are given by hundred-foot zones. The difference in level of correlated horizons is compensated for in the lower half of the section. In this composite log, heavy sand is found in the 600 to 700 foot zone and it is tentatively assumed that the top of this heavy sand approximately marks the base of the Beaumont clay.

Lafayette gravel.—Underlying the Beaumont clay is the Lafayette gravel, late Pliocene and perhaps early Pleistocene in age. This formation is composed predominantly of sands and gravels with intercalated clays and sandy clays. The Lafayette gravel is apparently about 900 feet thick. The whole section is so sandy in the southeast field that it is difficult to pick up the transition from the sandy Lafayette to the supposedly clayey Fleming. But farther out as is shown by the composite log, the transition is marked, and comes at 1500 feet. This is almost the normal depth for the base of the Lafayette and shows that 3000 feet out from the edge of the salt there has been little uplift since Fleming time. The Lafayette formation is non-marine.

Fleming clay.—Underlying the Lafayette gravel is the Fleming clay, undifferentiated Miocene and Pliocene. This formation is predominantly composed of clay with some sand, although farther west where the triple division of Lagarto, Lapara, and Oakville is possible, the latter two formations are distinctly sandy. The Fleming formation here is apparently about 1700 feet thick. In the main area of the southeast field, the transition to the underlying sandy Corrigan division can not be indicated with much certainty but in the composite log it is fairly well marked and comes at 3200 feet, where there is a

change in the character of the formation from 70 per cent clay to 70 per cent sand and "rock."

Fossils show that perhaps the Upper Miocene is present at 2800 feet in the Gulf Company's H. Masterson No. 1 slightly northeast of the southeast field. A collection of fossils obtained by R. F. Baker were determined by Dr. J. A. Gardner of the U. S. Geological Survey, as comprising the following: *Arca* ? sp.; *Arca transversa* var. *busana,* Harris; *Ostrea* sp.; *Venericardia* sp.; *Dosina* sp.; *Cardium* sp.; *Mulinia* sp.; *Corbula* sp. She states that "The fossils of Tertiary age and the scanty evidence which they afford indicates that they perhaps belong to the Upper Miocene." Some fragmentary fossils collected by John Anderson from the same depth in this well were examined by Dall who reported that the material contained hardly anything which was identifiable and that all he could find in it was part of an echinoderm which appeared to be the Eocene *Periarchus pilcussinensis* Ravenal, but there was only a part of the margin preserved. The preponderance of evidence would seem to be in favor of the probable Miocene age of the beds at 2800 feet in the well. As there was considerable open hole at the time of the blowout, which brought these shells to the surface, there is some possibility, however, that they came from the sides of the hole considerable above the 2800 foot level. The log of this well has not been obtained and exact correlation of the depth with the sections in the main southeast field is not possible, but by extrapolation of the structure contours it seems probable that the 2800 foot level in the H. Masterson No. 1 well is equivalent to the 2900 to 3000 foot level in the composite log and 200 to 300 feet above the base of the Fleming.

Corrigan sandstone.—Underlying the Fleming clay, is the Corrigan (Catahoula) sandstone of Oligocene and perhaps lower Miocene age. The thickness of the "Catahoula" is given by Deussen as 500 to 800 feet, while Dumble gives the thickness of the Corrigan as 450 feet. It seems not improbable that the base of the Corrigan has not been reached as yet by any of the wells, unless possibly by some of the deep wells close to the edge of the salt. As yet the underlying Jackson formation has not been recognized. Some of the deeper wells such as the Gulf

Prod. Company's W. C. Hogg Nos. 1 and 2 stopped in a black shale and sandy shale. At the base of the Corrigan, according to Dumble, clays come in which are in places lignitic. The black shale of the deepest wells may therefore be basal Corrigan. The Jackson formation, however, is also lignitic.

AGE OF THE DOME

In discussions of the age of salt domes, differentiation should be made between the age of the salt dome mound and the age of the salt dome proper, or more particularly, the time of the intrusion of the salt core. The salt dome mound in some cases, as for example at Avery's Island, has been formed by the upthrust of the salt mass and in such cases is of course of the same age as the last salt dome activity. But in other cases it seems not improbably to have resulted either from the formation of the cap rock or from the hydration of the anhydrite to gypsum. The cap rock is secondary and seems to have displaced rather than replaced the sediments. It might thereby of its own force cause a deformation of the surface long after the upthrust of the salt core had ceased. The calcium sulphate of the cap is not uncommonly deposited as anhydrite which later changes by hydration to selenite. But as at West Columbia there has been only a partial alteration of the anhydrite to gypsum and as the cap is thin or absent over the south part of the dome, the deformation above the present salt dome mound is probably not due wholly to the formation of the cap or the hydration of the anhydrite of the cap to gypsum. plain here which is of Pleistocene and probably late Pleistocene or Recent age. The mound represents a deformation of the plain here which is of Pleistocene and probably late Pleistocence age. The base of the Lafayette (late Pliocene) has apparently suffered uplift some 400 feet. This uplift is greater than could possibly be explained by the development of the cap rock or its hydration and indicates that there has been an upthrust of the salt mass since late Pliocene time. The top of the salt is about 2600 feet above the original position of the now upwarped Corrigan sandstone. It would therefore seem probable that the greater part of the deformation and intrusion of the salt came between the late Oligocene and early Pliocene.

ORIGIN OF THE SALT DOME

The origin of salt domes is a perplexing and disputed question. The discussion of the problem should probably be re-

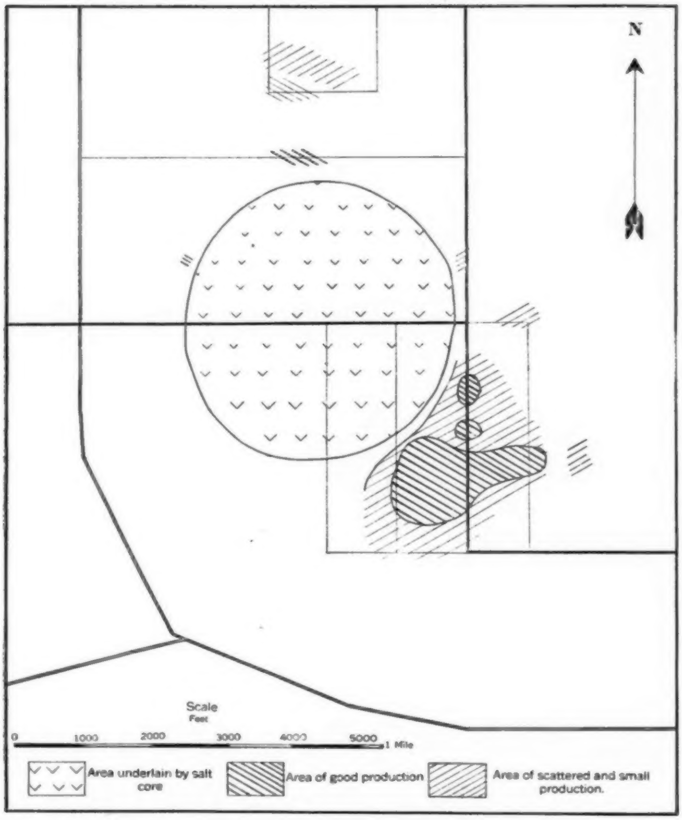

Fig. 4. Sketch map showing the position of areas of production with reference to the area underlain by salt.

solved into (a) the origin of the salt, (b) the *mise-en-place* of the salt core, and (c) the origin of the cap rock.

The cap rock seems probably to be secondary and to be especially associated with salt domes. Although gypsum and

anhydrite are found away from the vicinity of known salt domes they are characteristically found associated with these. The very heavy beds, hundreds of feet in thickness, are found only on salt domes. No satisfactory petrologic study of the cap rock has been made and the significance of the banding is not known. In regard to the formation of the cap the consensus of opinion of geologists working on salt domes in the Gulf Coast Region seems to be in favor of the conception that the formation of the cap rock marks one of the last phases of salt dome activity, that it did not take place until the salt core was essentially in its present position, and that it is due to the interaction between the normal waters of the invaded sedimentary beds and solutions accompanying the salt dome. The European view of the origin of the cap rock is that it is a residual deposit resultant upon the solution of an impure salt mass[1]. Although apparently warranted in the case of the German salt domes, this explanation is definitely impracticable in the case of the Gulf Coast salt domes of Texas and Louisiana. The objections to this explanation in the case of these domes are two: (1) that the main salt mass of the American domes is of a high degree of purity. The so-called "white salt" which composes the bulk of the salt mass in the Avery Island mine[2] contains 99.10 percent Na Cl, while the material from the dark streaks contained 96.53 percent Na Cl and 3.21 percent $CaSo_4$. The cores of salt seen by the writer from other salt domes of this region have all been composed of clear, transparent, colorless grains of salt with no impurities which could be seen by simple megascopic examination. (2) The other objection is that the cap does not cling closely to the surface of the salt mass as would residual material. The cap rock is usually spoken of as a single mass of anhydrite, gypsum or limestone mantling the salt core. But in reality, the cap may be separated from the salt by sand or clay and may consist of masses of cap rock separated by sands and clays. The conditions which favor the formation of the large masses of cap in close proximity to the

[1]C. E. Harbort: Neu U. Umbildungen im Nebengestein der norddeutschen Salzstocke-Monats bercht d. deutschen geol. Gesellsch, Vol. 65, pp. 6-16, 1913.

[2]G. D. Harris, Geol. Surv. of La., Report of 1907, Bull. 7, p. 16.

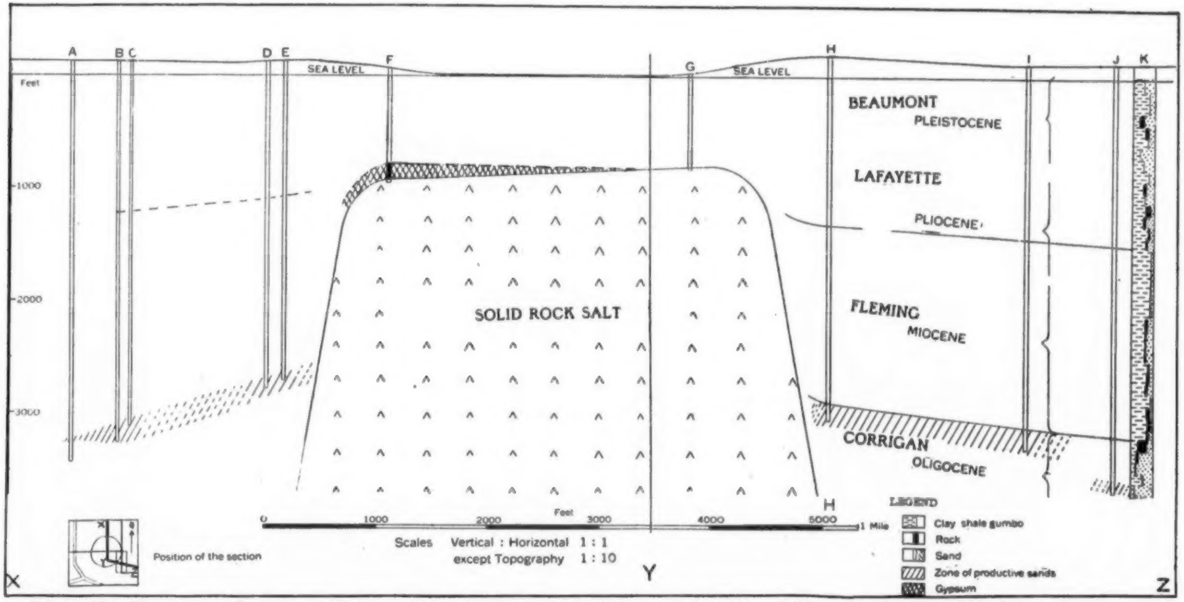

Plate II. North scuth-east southeast cross section of the West Columbia field. A. Barclay-Meadous Kansas and Gulf No. 1. B. Humble Oil & Refining Company's Robinson No. 1. C. The Texas Company's Abrams No. 2. D. The Texas Company's Abrams No. 1. E. The Texas Company's Hogg No. 49. F. Palaceos Oil Company's No. 2. G. The Texas Company's Hogg No. 88. H. The Texas Company's Arnold No. 18. I. The Texas Company's Hogg No. 40. J. Gulf Prod. Company's W. C. Hogg No. 1. K. Composite log.

salt mass seem also to favor the formation of less beds of similar rock intercalated among the sands and clays of the horizons immediately above. On the flanks of the dome, furthermore, the cap in some cases projects out a considerable distance into the surrounding sediments as a lens rather than merely clinging to the edge of the salt.

In regard to the origin of the salt core there semes to be a growing consensus of opinion among these geologists that the salt core has been intruded into the surrounding sediments. The mechanism of the intrusion of the salt and the source of the salt are however much disputed questions.

The present study of West Columbia sheds little light on these questions, except to emphasize the intrusive character of salt domes. With its circular outline and nearly vertical sides it closely resembles a volcanic plug. The analogy ceases, however, when the doming around a salt dome is considered. The usual lack of doming around a volcanic plug and its presence in the case of a salt dome might be explained by the fact that the mechanism of intrusion of the former may include overhead stoping, solution, and blow-piping and that the intruded material is liquid and that furthermore a small vent may be enlarged by the transportation to the surface of debris from the walls. The salt, however, does not include within its mass or assimilate any of the country rock and judging from the manner in which it drags the adjacent sedimentary beds with it, must have been intruded as a fairly solid mass. Another theory of the origin of salt domes, which has some attraction is that of deposition of the salt from brine solutions ascending at the intersection of fault planes. But there is grave doubt of the permissability of postulating a fault fissure which remains open through 4000 feet or more of such unconsolidated sediments as are found in the West Columbia region sufficiently long for an upward current of water to become established, and if such a current did become established, there are questions to be answered as to why the ascending waters were not deflected into some of the drier sands of such a series as the Corrigan, or diluted by the artesian sands of such a series, or why the equilibrium of the ascending brine was not upset by admix-

ture with the waters of some such sands with consequent greater deposition at these levels. Such does not seem to be the case. It is also notable that wells within 800 feet of the almost vertical edge of the salt have no salt lenses.

An extended discussion of the origin of salt domes will not be included in this paper. Those interested in the question should consult the papers by Harris[3], Dumble[4], De Golyer[5], Rogers[6], Hahn[7], and others.

OIL AND GAS

The indications which led to drilling at West Columbia were gas seeps, paraffin dirt, and oil shows. There is a gas seep with a good paraffin dirt bed on the west side of the hill on which the Texas Company's camp is located on the west side of the dome. Well No. 3 of the West Columbia Oil Company was drilled in the center of this bed. On the east side of the dome, on the Arnold tract about where the first Equitable wells were drilled, there were, according to report, gas, oil and sulphur seeps at the surface. The first shallow wells there found oil at shallow depths.

The main oil sands of the old, or southeast, field are found between 2800 and 3350 feet. There is roughly a division of an upper set of sands and a lower, separated by a shale break. This division is not hard and fast. Indeed, in some wells no division of this sort is possible, productive sands being found in an intermediate zone. The individual oil sands vary considerably in thickness. The Crown Oil and Refining Company's Marmion Nos. 1 and 2, Gulf Prod. Company's Eyers Nos. 1, 2, and 3, have 40 foot sands. The Humble Oil and Refining Company's Coon No. 1 has screen set, at 5 different places and has one 30 foot sand, a 50 foot broken zone and three

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[3]Harris, G. D., Rock salt in the state of Louisiana, Bull. 7, Geol. Survey of Louisiana, 1907.

[4]Dumble, E. T., Origin of the Texas salt domes, Bull. A. I. M. E., No. 142, 1918

[5]De Golyer, E. L., The theory of the volcanic origin of salt domes, Bull. A. I. M. E., No. 19, 1918.

[6]Rogers, G. S., Intrusive origin of the Gulf-coast Salt domes, Ec. Geol. Vol. XIII, No. 6, 1918.

[7]Hahn, F. F., The form of salt deposits Ec. Geol. Vol. VII, No. 2, 1912; Grabau, A., Principles of salt deposition, 1920.

producing horizons in sandy shale. The Texas Company's Hogg No. 11 has set screen to cover about 180 feet of broken formation embracing one 25 foot sand and one 35 foot sand and several thinner sands. The H. O. and R. Company's Bashara No. 3 is producing from a 40 foot sand and 30 foot broken zone.

On the extreme east of the oil field, 1000 feet east of the main part of the field, the G. P. company's W. C. Hogg wells are producing at 3675 feet from a black sandy shale. This is stratigraphically a deeper horizon than the sands of the main field.

In the new field, on the north side of the dome, the pay sands of the Texas Company's Abrams well and Hogg No. 49 are at a depth of about 2275 feet, while on the south edge of the Jackson subdivision they are around 3200 feet; the Abrams No. 2, 3125 feet; H. O. and R. Company's Nos 1 and 2 Robinson, 3270 and 3297 feet respectively; and the Barclay well at 3290 feet. The sand here is some 40 feet thick and has a limestone lense in the middle. The wells which have gone too deeply into the sand have had trouble with water.

Halfway between the new field and the old field and within 700 feet of the edge of the salt, the Big Oil Company has brought in a well at around 2500 feet and in similar position on the northwest, the H. O. and R. Company has brought in a well at about 3200 feet.

A fair gas pressure is found over most of the dome. Some of the early shallow wells had severe blowouts at a depth of a few hundred feet. The H. O. and R. Company's Japhet No. 16 was a gasser at 1800 feet. The Texas Company's Arnold No. 1 had a flow of some seven million cubic feet of gas at 2650 feet and the Big Belt Oil Company's Hogg No. 51 had an extremely severe blowout at 2225 feet. The gas caught fire as it blew out. The flow was not measured but according to one estimate was of the magnitude of seventy-five million cubic feet. The Texas Company's Abrams No. 1 and Hogg No. 49, a few hundred feet to the east, are said to have encountered the same gas sand but to have held the gas in.

The oil at West Columbia does not vary as much as in some of the other fields, as for instance, Hull, where there is a range

in gravity of the deep oil from 19 to 38 degrees B., with many fair wells producing oil with a gravity of over 30 degrees B. In the southeast field, on the Japhet lease, the gravity of the oil varies from 19 to 24 degrees B. with the maority of the wells producing oil of 22 or 23 degrees B. The adjacent Sun lease and G. P. Company's Eyres lease, produce 19 to 23 degrees B. oil with most of the wells producing oil of 21 or 22 degrees B. The H. O. and R. Company's Girard and Marmion lease produce 21 to 23 degrees B. oil and also some wells that are reported as producing oil of a gravity of only 15 degrees B. The Texas Company's Hogg wells produce oil for the most part of 22 to 23 degrees B. gravity. The gravity of the oil from the Arnold lease is mostly of 22 degrees B.

The wells in that part of the Hogg subdivision north of the Japhet lease produce oil of 23 to 24 degrees except the G. P. Company's McMeans No. 1 and the H. O. and R. Company's Bashara No. 3, which produce oil of 38 to 42 degrees B. respectively. These are the only two wells which have produced oil of this gravity. In the new or north field, the gravity of the oil varies from 21 to 22 degrees B.

On the northeast of the Hogg subdivision the G. P. Masterson well had oil of 29 degrees B. On the west flank of the dome the Texas Company's Hogg (Kaiser) No. 5 had a good showing of 26 degrees B. oil from around 2500 feet. In the various old shallow wells, a thick heavy oil was obtained at a depth of a few hundred feet.

TEMPERATURE AND GEOTHERMAL GRADIENT

The temperature of the oil varies from 90 to 112 degrees F. and the temperature gradient in the oil wells from 65 to 165 feet per degree with a few cases of much lower and much higher temperature and much lower and much higher gradients. The data at hand are for the most part reported by the pipe line companies for the temperature of the initial production and are supposed to have been taken at the well immediately after its completion. No further information is at hand in regard to the method of taking the temperature. The data contain many inaccuracies, but it is believed that with the large number of observations available, the tendency to grouping

around certain means both areally and on graphs allows some conclusions of a fair degree of probability to be drawn.

The temperature gradients have been calculated according to the formula:

$$\text{Gradient} = \frac{\text{Depth of Producing Sand.}}{\text{Temperature of Oil} - \text{Mean Annual Air Temperature}}$$

The mean annual air temperature, 69 degrees F. of Houston, is assumed to be the mean annual temperature of West Colum-

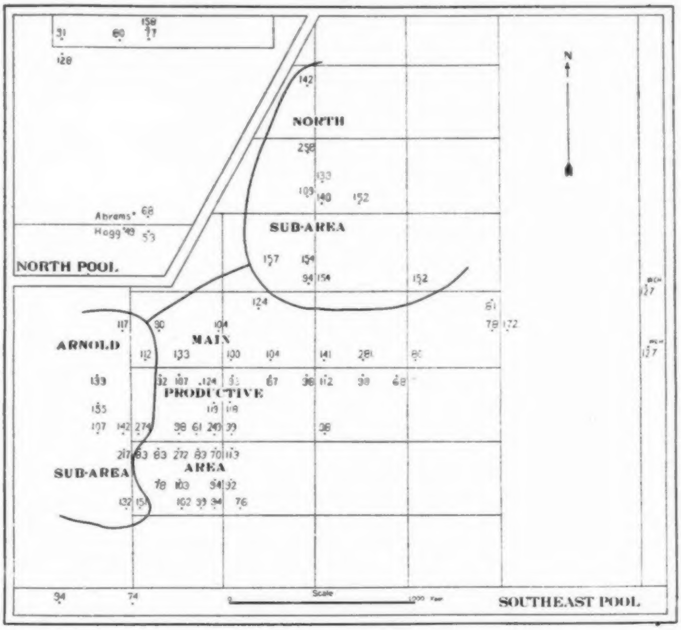

Fig. 5. Map showing distribution of thermal gradients.

bia, and the mean annual ground temperature at the surface is assumed to be the same as the mean annual air temperature. In most cases, the exact depth and thickness of the producing sands is not known except to the nearest 100 feet or 50 feet. But the inaccuracies thus introduced are in most cases not large.

From the accompanying map Fig. 5 and graphs Figs. 7-10 it is believed that the following conclusions are warranted: (1) That the producing area can be divided into several sub-areas in each of which the normal temperature and geothermal gradient is different from the normal temperature and geothermal gradient of the others. (2) That the gradient tends to steepen with increasing depth of the oil sand. (3) That the gradient tends to steepen with the increasing productivity. (4) That the gradient tends to be steeper in the later wells

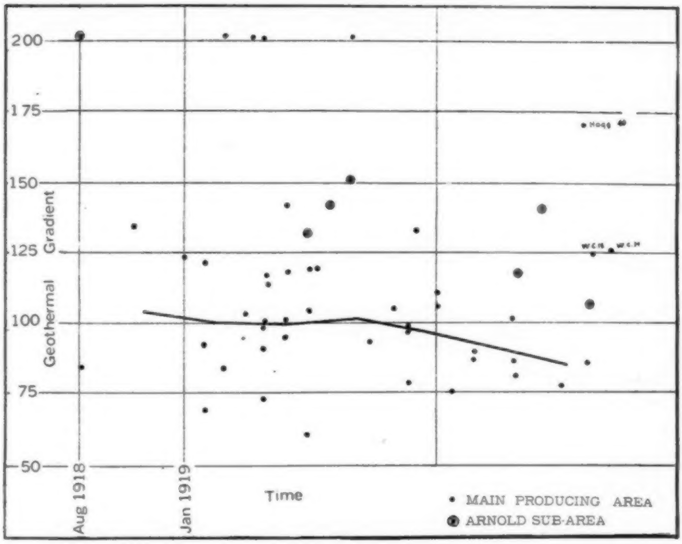

Fig. 6. Digram showing the relation of geothermal gradient to time.

drilled in a given area. (5) That there is a tendency for the later wells to be slightly deeper than the earlier wells. (6) That within the productive zone, depth has little influence on productivity.

The map Fig. 5 shows the areal distribution of the gradients. In the area north of the Japhet lease in the north of the Hogg subdivision the gradients approach very closely to 150 feet per degree.

In the main part of the productive area of the Southeast field, the gradient tends to be above (numerically less than) 110 feet per degree. Of the exceptions, the gradient in three cases is so exceptionally low that it would seem probably to reflect some abnormality and the others are mostly not far from 110 feet. The higher limit for the gradient would seem to be around 80 feet per degree F.

The Arnold tract and part of the west edge of the Hogg sub-

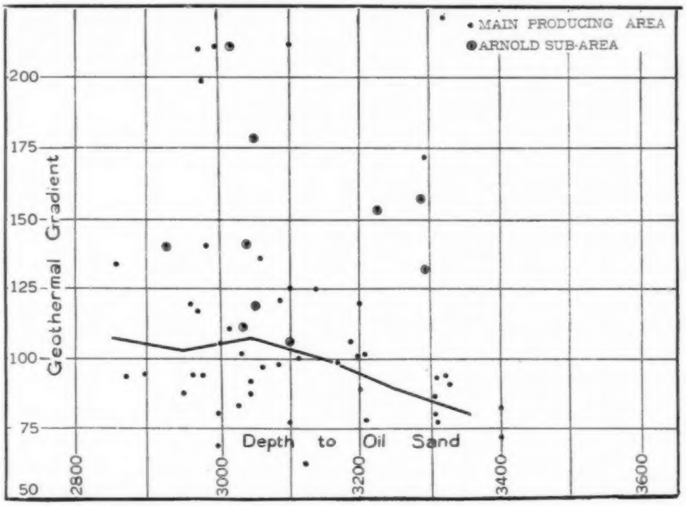

Fig. 7. Diagram showing the relation of geothermal gradient to depth to oil sand.

division seem to have a very much lower (numerically higher) gradient. In more cases where data are available there is no gradient below 100, only one case below 110 and in most of the cases the gradient is above 130. The situation would seem to suggest very strongly that the normal gradient is different for the Arnold tract and for the main part of the productive field. In the new or north pool, there is much variation in the gradient, but it tends to be slightly higher than in the southeast pool.

Fig. 6 shows the geothermal gradient plotted with reference to the date of completion of the wells in the main producing field and the Arnold sub-area. The distribution of the points is much more scattered than in the preceding graph but if the points of the Arnold sub-area of the G. P. Co.'s two W. C. Hogg wells are really beyond the limits of the main productive area, of the Texas Co.'s Hogg No. 4 which is on the outer edge of the area, and of four wells which have a very exceptionally low gradient are neglected, the points are rather symmetrically located around the median line sloping at the rate of about 1 foot per degree F. per month. The distribution of the points of the Arnold sub-area shows a similar tendency but the points are too few to warrant any conclusions.

The graphs of the gradient plotted against depth for the

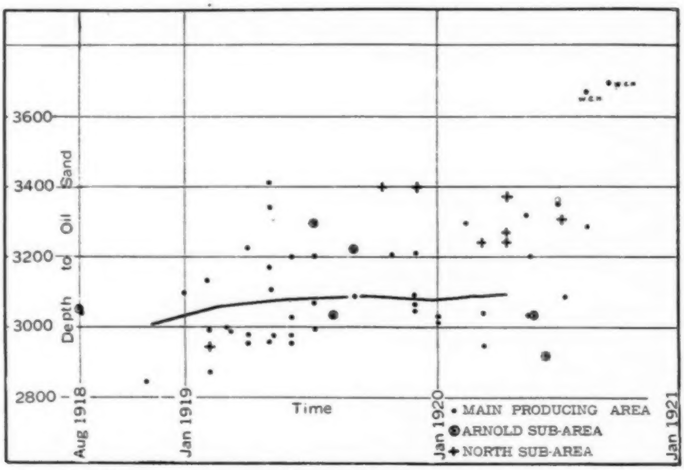

Fig. 8. Diagram showing the relation of depth to oil sand to time.

main southeast field and the Arnold tract are shown in Fig. 7. The points for the Arnold tract and for some of the immediately adjacent wells of the Hogg subdivision which seem to belong to the same sub-area are specially marked. With the exception of the points representing Hogg 40 and three points with abnormally low gradient, the points of the main produc-

ing area fall within a narrow ovate area whose axis dips at the rate of 5 feet per 10 F. per 100 feet of depth.

The graphs of the mean gradient per 100 feet are shown by the line. In figuring the mean the points representing the gardients in the Arnold sub-area and the very abnormally low gradients were neglected. The inclination of this median line seems to indicate that within the main producing field, the gradient increases with the depth of the producing sand. The points representing the Arnold sub-area are widely scattered and, if anything, would seem to indicate the reverse tendency, that the gradient lessens with depth, but the points are too few to warrant conclusions.

Fig. 8 shows the depth of wells in the main producing field, the north sub-area and the Arnold sub-area plotted with reference to dates of completion. With the exception of the points representing the two G. P. Co. W. C. Hogg wells, the north-sub area and the Arnold sub-area, the points lie fairly well distributed around a fairly even median line which shows a total mean increase of depth of the wells of 100 feet in 17 months or 190 feet in 20 months. If allowance is made for the increase of gradient with increase of depth with time, there is left a mean increase of gradient of 8 feet per degree F. in 17 months of 10 feet per degree F. in 20 months. So that independent of any tendency toward increase of gradient with time due to increase of depth of drilling wells with time, there is a tendency toward an increase of gradient with time at the rate of about 0.5 feet per 1°F. per month, which is equivalent to a mean increase of temperature of about 0.15° F. per month in a 3000 foot oil sand.

This variation of the gradient with time is perhaps suggestive of reactions of the oil with the waters which for a long time have been invading the field but it would also seem possible to explain in part the increase of temperature with time by the heat brought up by oil and water coming up the dip. If the increase of gradient with depth holds for the ascending oil and water a movement 400 feet vertically would account for the observed increase in gradient since the early days of the field.

Fig. 9 shows the gradient plotted against the initial production. With the exception of Japhet No. 5, Hogg No. 40, and three wells which had a very abnormally low gradient, the points lie fairly uniformly in a zone which has a mean slope of 1.8 feet per degree F. per 1000 bbls. It is worthy of note that the wells of the new or North pool lie within this zone and that if the median line is extended to the points representing Abrams No. 1 and Hogg No. 49 the mean slope is 1.7 feet per degree F. per 1000 bbls. The points representing the north sub-

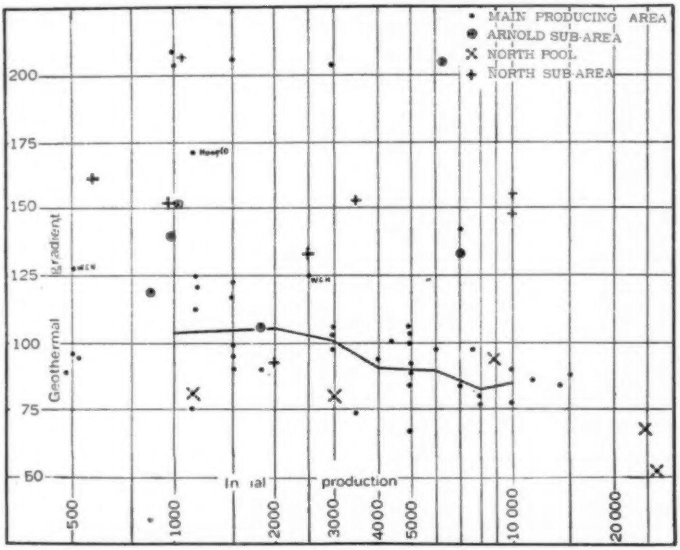

Fig. 9. Diagram showing the relation of geothermal gradient to initial production.

area and the Arnold sub-area, for the most part, lie well without this zone.

Fig. 10 shows the initial production plotted against depth to the oil sand. From inspection of the figure it can be seen that although the productive sands of the main producing field occur for the most part between 2950 and 3100 feet, there is no tendency for the amount of initial production to vary with the

depth of the productive sand. Although the largest gushers of the field have been brought in within the last six months, there were many large gushers of 5000 to 15000 barrels initial production in the early days of the field, and there has been no general increase of the amount of initial production with time. If anything, the initial production within the main productive

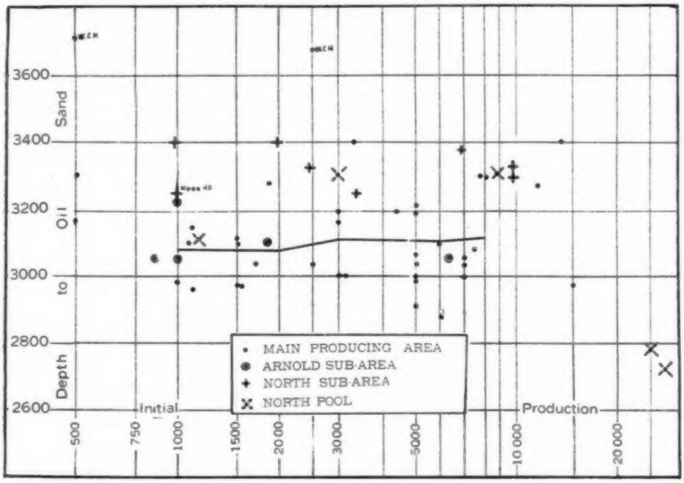

Fig. 10. Diagram showing the relation of depth to oil sand to initial production.

area has dropped with time as is normal. The increase of gradient with the amount of initial production is therefore independent of increase of gradient with depth or with time. This relation would seem suggestive of the influence of friction but at present the data are not at hand to determine whether or not this is the case.

The mean gradient is 102 feet per degree F. at 3000 feet. The mean gradient in the early days of the field was 101 feet per 1 degree F. and the mean gradient for wells of an initial production of less than 2000 barrels is 103 feet. The original temperature of the oil would therefore seem to have been about 98.4° F. at 3000 feet and 103.8° F. at 3200 feet.

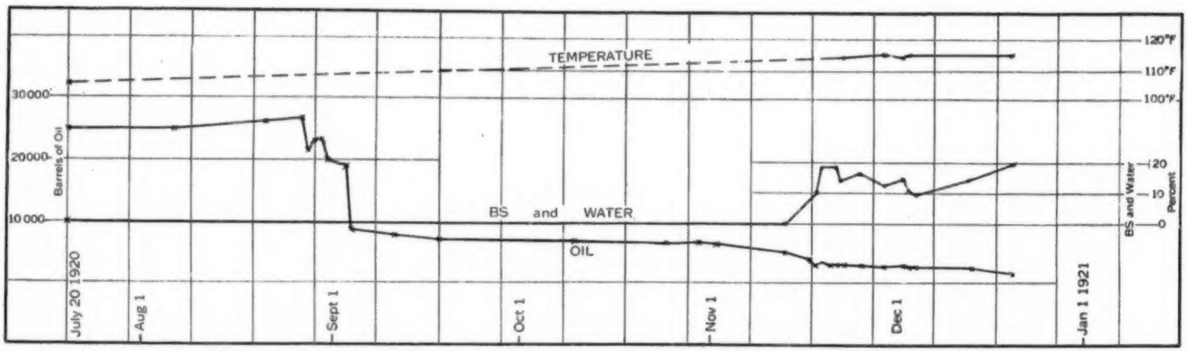

Fig. 11. Diagram showing the relation of temperature, production of oil, BS and water to time.

Although perhaps of no real significance, it is interesting to note in case of the Abrams No. 1 which caused considerable anxiety at first on account of its high temperature at shallow depth, that if the gradient and temperature is computed as for a 1000 barrel well witn allowance of 1.7 feet per 1 degree F. per 1000 barrels, they are respectively 109 feet per 1 degree F. and 94.6° F. The normal gradient and temperature for this depth according to the rates prevailing in the main producing area of the oil field would be 112 feet per degree F. and 93.8° F. The agreement is strikingly close.

The temperature and geothermal gradients of the preceding discussions are those of initial production. The data at hand in regard to variation of the temperature and geothermal gradient of individual wells with the passage of time is fragmentary. In the case of Hogg No. 49, the offset to Abrams No. 1, there had been little change in the temperature up to the time when both wells began to make much water and B. S. The temperature then rose 3.5° F. but a short time later dropped 2 degrees coincidental with a considerable drop in the water and B. S. and rise in the amount of oil, immediately before the sanding up of the well. What data are at hand concerning Abrams No. 1 are shown in Fig. 11. The initial temperature was 105° F. Within a week after the appearance of the water and B. S. the temperature was 115° F. and it shortly rose to 116° F. The H. O. & R. Co.'s Robinson Nos. 1 and 2 and the G. P. Co.'s A. Masterson all showed an increase of temperature of 2° to 3° F. after a life of some two months.

The normal geothermal gradient formerly was considered to be 60 to 70 feet per 1 degree F. but with the more extensive geothermal data now available, it is recognized that it is impossible to give any gradient which will be normal for any considerable area.

The data available for the geothermal gradient of the Gulf coastal plain and adjacent portion of the Atlantic coastal plain are given in (Table I). The data given are for the deepest wells only and for cases in which Darton[8] believes the deter-

[8]Darton, N. H., Geothermal Data of the United States. U. S. Geol. Survey, Bull. 701, 1920.

mination to be fairly reliable. As the data for Georgia, Florida, Alabama, Mississippi, and Louisiana are for depths of less than 1700 feet and as the relation of the temperature gradient between 1700 and 3300 feet to that from the surface to 1700 is not known, these are not exactly comparable to West Columbia where the depth ranges from 2600 to 3200 feet. But if, as would seem not unlikely, the geothermal gradient for depths of 1000 to 1700 feet is of the same general magniture as for depths of 2600 to 3300 feet, the geothermal gradient at West Columbia is of the same general magnitude as that prevailing in South Carolina, Florida and Louisiana. The gradient is of the same magnitude as that at Hempstead and Port Arthur, the only localities in the same region as West Columbia which have been studied. The gradient is very much lower at West

Table I. Geothermal Gradient in the Gulf Coastal Plain and Adjacent portion of the Atlantic Coastal Plain.[a]

		No. of Wells	Depth	Gradient per degree F.
South Caroline (Charleston)		5	2000	58-61
Georgia (Albany)		1	1320	119
Florida (San Augustine)		1	1390	81
Alabama Linden (Marenjo Co.)		1	1200	143
Mississippi	Canton	1	1021	109
Mississippi	Vicksburg	1	1100	211
	Biloxi	1	900	62
"	Port Arthur-Jefferson Co.	1	1400	128
"	Temple Bell Co.	1	1350	73½
"	San Antonio	1	1950	50
"	Austin-(Travis Co.)	1	1875	51
"	Manor	1	2560	48½
"	Corsicana	3	2500	40-41½
"	Fort Worth	1	3250	18½
"	Waco	8	1600-1900	49-55
"	Marlin Falls Co.	1	3330	41½
"	Batson Oil Field	2	1200	210-34
"	Saratoga	1	958	30
"	Sour Lake	1	985	31

a Data given by N. H. Darton: Geothermal Data of the United States U. S. G. S. Bull. 701, 1920.

Columbia than at other localities in Texas where the gradient is known. The depths at Manor, Corsicana, Fort Worth, and Marlin, are comparable to those at West Columbia but the

gradients at Manor, Austin, Fort Worth, and at Waco are probably abnormal, due to factors connected with the Balcones fault.

Compared with the gradients given for Batson, Saratoga,

Table II. Geothermal Gradient in other oilfields.

		No. of Wells	Depth	Gradient
California				
Fresno Co.[a]		1	2077	37
Kern Co.[a]		2	2525	50-91
Sunset Midway Field[b]				
Within 2 miles of outcrop		1	below 2500	124
Within 2-4 miles of outcrop		9	"	97
More than 4 miles from outcrop		11	"	158
Water Wells		4	"	63
Oklahoma				
Bartlesville[b]		1	1275	51
Ohio				
Findlay[b]		1	3000	96
West Virginia				
Wheeling[b]		1	4.462	75
Mexico				
Vera Cruz[b]		1	2.276	47
Texas	Hempstead Wells Co.	1	1131	97½
"	Drake Salt Works	1	1011	123
Louisiana	Belle Isle	1	1625	82
"	Leland	1	1550	78
"	New Orleans	1	1229	92

a Rogers, G. S., Chem. Relations of the Oilfield Waters in San Joaquin Valley, California, U. S. G. S. Bull. 653, 1917.

b Rogers, G. S., Geochemical Relations of the oil gas and water, Sunset Midway Oilfield, California, U. S. G. S. Prof. Paper 117, 1919.

and Sour Lake, that at West Columbia is very low. In connection with the gradient at Batson, Rogers[9] makes the comment that the high gradient is due to the fact that the oil and water have probably ascended steeply from a considerable depth. If this use of the temperature is a criterion of the movement of oil upward from great depth, the geothermal gradient at West Columbia would indicate that the oil has not ascended any appreciable distance.

The geothermal gradients for comparable depths in other oil fields is given in Table 2. In California, the gradient in Fresno and Kern counties seems to be higher, and in the Sunset-

[9]Rogers, G. S., U. S. Geol. Survey, Prof. Paper 117, p. 42, 1919.

Midway field it is of about the same magnitude as West Columbia. The gradients available for West Virginia and Vera Cruz respectively are much higher than at West Columbia, while that at Findlay, Ohio, is of the same magnitude. But on account of the known variations of temperature and geothermal gradient within a single field, comparison with isolated determinations of temperature and gradient is of no great significance.

PRODUCTION

The production of the West Columbia field has been as follows:

1918	--	136,350 barrels
1919	--	8,128,809 barrels
1920	--	10,563,748 barrels
Total production to 31 Dec., 1920		18,828,907 barrels

The crest of production for the old field was reached in September 1919, when the mean daily production was around 35,000 barrels. By the first of July, 1920, the production had fallen off to 18,000 barrels mean daily production and was falling on the average about 500 barrels mean daily production per week. The completion of the Texas Co.'s Abrams well raised the production to its maximum thus far, for the field as a whole, 52,725 barrels mean daily production for the week of July 31st. The present production (week of January 8, 1921) is around 34,000 barrels mean daily production. This rate has been exceeded by—

Spindletop	1902	with a production of 17,420,949 bbls.
Batson	1904	with a production of 10,904,737 bbls.
Humble	1905	with a production of 18,066,428 bbls.
	1915	with a production of 11,061,802 bbls.
	1916	with a production of 10,925,805 bbls.

From the production curve of the oil field, it can be estimated that the future production will amount to at least some 7 to 10 million barrels. Extensions of the old field are likely to cause the actual future production to exceed these figures. What the total production of the new field is likely to be can not be estimated at present.

The Gulf Coast record for mean production per acre for the field is given by Suman[10] as that of Spindletop 141,598 barrels per acre. Although the really very productive portion of West Columbia dome comprises only about 55 acres, the total productive area of the old or southeast field at West Columbia, including surrounding territory probably drained by the field is about 120 acres. The mean production per acre to date is 123,090 bbls. The probable future production per acre of the area now producing will be between 58,000 and 80,000 barrels so that the ultimate figure for the mean production per acre for the old field will probably be around 200,000 barrels, or if the 55 acres which has produced nine-tenths of the oil, alone is considered the figure for the per acre production would be well over 300,000 barrels.

The records of production for two small and compact leases, the Crown Oil & Refining Co.'s Marmion and Olchewki lease and the Sun Co.'s Robertson lease, are available. The curves of mean daily production by weeks for the Crown O. & R. Co. and for the Sun Co. are shown in Fig 13. The production of the Crown O. & R. is settled. There are already seven wells on the two acres and as can be seen from the curve of production the completion of the last well, Marmion No. 4 scarcely affected the rate of production for the two leases. By use of the curve it is possible to calculate that the future production of these two acres will be 28,000 bbls., if production is abandoned when the mean daily rate of production drops to 20 bbls. or 63,000 bbls. if it is not abandoned until the rate drops to 1 bbl. per day. The total production of these two acres has been about 1,887,000. The ultimate mean production per acre will be between 958,000 and 975,000 barrels. The production on the Sun Co.'s Robertson lease has been at a very much smaller rate. Five wells have been completed on the five acres. The completion of No. 5 has not appreciably affected the production. By use of the plotted curve it may be calculated that the completion of No. 5 has resulted in an increase of production of 4000 barrels, a total increase of production of slightly over 12,000 barrels. The production of this part of the lease, there-

[10]Suman, John, Oil Weekly, Oct. 23, 1920.

fore, seems fairly settled. The completion of the wells in the southeast of the lease will however, undoubtably cause a moderate increase in the total production. The total production of the lease to date has been 388,430 barrels. The probable future production of these wells will be between 15,000 and 25,000 bbls.—not counting the future production from the southeast portion of the lease. If the assumption is made that the present wells draw about 60 percent of the area of the lease, the ultimate mean production per acre will be about 138,000 barrels. This is slightly over the mean production per acre for the old field as a whole.

The difference in productivity can be explained partly by the time relations of the offsets. The Sun Co.'s wells came in at the same time as two of their offsets, had one month's start of No. 1 and three months start of No. 2 and in one case the offset had a one month start of the Sun Co.'s well and in one case a three months start. The Crown O. & R. Co's. wells came in at the same time as the offset in two cases had two months start in six cases, a three months start in one case and a four months start in one case and in one case an offset had a one month's start. The Sun Co.'s wells therefore can be said to have come in at the same time as their offsets while the Crown O. & R. Co.'s wells averaged slightly less than a two months start in their offsets. The difference in productivity is so great however, that it would seem probable that there is also considerable difference in the actual capacity of the oil containing sands.

Fig. 11 shows the graph of the production of the Texas Co's. Abrams No. 1, the so called "Wonder Well" of the Gulf coast fields. This well blew in on September 20, 1920 when a Hughes roller bit went through a lense of hard rock into a pay sand below. For six weeks the well flowed at the rate of between 25,000 and 28,000 barrels per day of pipe-line oil. During the first week in September the well bridged over. Up to this time it had been flowing between the casing and the drill stem. The latter was then uncapped and the wel began flowing again at the rate of 10,000 bbls. per day of pipe line oil through the drill stem and water courses in the Hughes bit. The production dropped slowly from 10,000 to 6,000 barrels per day.

During this time, the offset well Hogg No. 49 was brought in with an initial production of 28,000 to 30,000 barrels, but with no effect on the rate of production of the Abrams well. In the middle of November, B. S. appeared in both the Abrams and Hogg wells and two days later salt water, and at the same time production dropped from about 6000 barrels of clean oil to

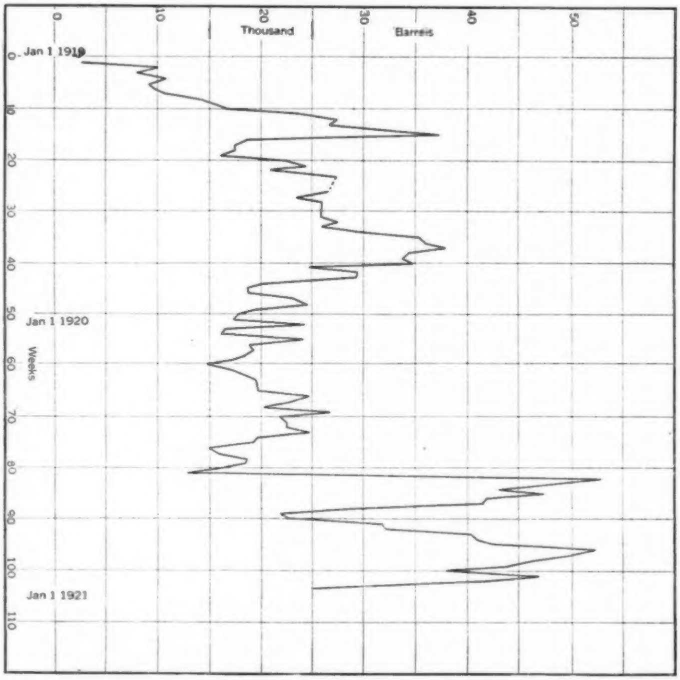

Fig. 12. Graph showing daily production of the whole West Columbia field, by weeks, Jan. 1919, to Jan. 1921.

4,500 barrels, 8 percent water and B. S. in the case of the Abrams well and from 25,000 barrels of clean oil to 15,000 barrels 20 percent water and B. S. in the case of the Hogg well. The production in the Abrams well then dropped slowly to 3500 barrels and then 3000 barrels and is now between 2000 and 3000 barrels. The total production of the Abrams No. 1 up to

January first has been about 1,693,000 barrels of oil with a total value of slightly more than five million dollars.

West Columbia has had many large wells, although none of them were as large as the Abrams No. 1 or Hogg No. 49. It has had 4 wells with an initial production of 5000 barrels per day or more, as follows:

Thousand bbls. per day	5	6	7	8	9	10	11-15	16-20	21-30
Number of cases	4	3	2	3	1	4	3	1	3

During 1920, there were drilled 95 wells, of which 72 or 75.8 percent were successful completions. They had an average initial production of 3349 barrels. This was three times as large as the next largest average initial production among the Gulf Coast pools and eight times the mean average initial production for all the pools.

NOTES ON OPERATION

On account of the soft and unconsolidated sediments which make up the larger part of the section in this region, the only system of drilling used is the hydraulic rotary system. When rock too hard to be drilled easily with the fishtail bit is encountered, a Hughes roller bit is used. The derrick used is 112 feet high with a 24 foot floor. On wells now drilling where a large gusher is expected, the Texas Company is using a derrick with the floor raised 5 feet above the ground so that the pipe can be reached easily below the mouth of the casing. A heavy rig is used, most commonly a heavy Oil Well Supply or Lucey Special, with a 12x12 engine and 40-60 horse power boiler. On the deeper wells now drilling, the Texas Company is using a twin engine in order more easily to handle the deep strings of drill stem and casing. Four inch upset drill stem, most commonly 12.63 lb. per foot, is used until the 6 inch casing is set and from then on 3 inch drill stem. From 600 to 900 feet of 10 inch surfacing casing is set and in some cases a few joints of 12-inch casing in addition. In a few cases 12-inch casing is set instead of the 10-inch. Some 3000 to 3200 feet of 6-inch or in some cases 8-inch casing is set for the deeper string. Where a 3200 foot string is set, 1000 feet of 23-50 lb. to the foot casing is set on the bottom and 2200 feet of 19.46 lb. to the foot on top.

The screen set most commonly is 80 mesh 4½-inch, or less commonly 6-inch or 3-inch, with a back pressure valve on the bottom. The amount of screen set varies with the amount of sand to be included and varies from a short single joint to 150 feet. In some cases there are several lengths set at different depths with blank pipe between. The time necessary to drill and complete a well varies very considerably but averages about 112 days for a 3150 foot well. Some wells have been drilled to that

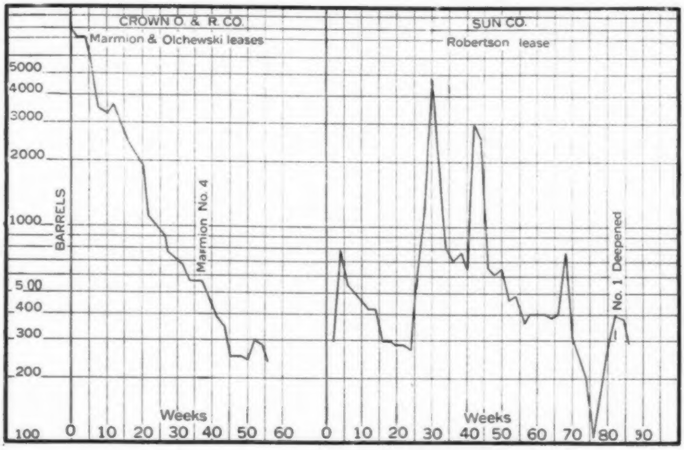

Fig. 13. Graph showing production of the Crown O. & R. Co.'s Marmion and Olchewski leases and the Sun Co.'s Robertson leases, by weeks.

depth and successfully completed in less than half this time. The cost of drilling a 3200 foot well at West Columbia is between $35,000 and $40,000. Contract drilling is at the rate of $6.00 a foot for drilling and $5.00 an hour for reaming and running core barrels, with the company supplying derrick, casing, fuel and water.

Many of the wells, especially the larger gushers, flow for many months, some of them with the drill stem and bit still in the hole. Abrams No. 1 flowed at the rate of 25,000 bbls. per day for a month and a half from an open hole and between drill stem and casing, and for 4 months it has been flowing at the

rate of 10,000 to at present 3500 bbls. of oil per day through the drill stem and water holes in a Hughes roller bit. When a well can no longer be made to flow, it is put on air and when it can no longer be made to flow on air it is put on the pump. The pumping is by standard rigs, locally built and run by individual light steam engines. Two and two and one-half inch pipe and 5-8 inch sucker rods are used. The Humble O. & R. Co. is at present installing an electric pumping system.

Many of the large producers, especially the gushers, produce clean oil which can be run directly into the pipe line. Most of the old wells and many of the new wells produce much B. S. and water. The amount of B. S. and of water occurring in the initial prouction of some of the wells at West Columbia is shown in the following table.[11] In some of these cases where the B. S. and water were high in the initial production, the water and B. S. were later successfully shut off.

Per cent		0	1-5	6-10	11-15	16-20	20-30	30-40	40-50	50
Water	Number of cases	8	3	2	2		3		7	7
B. S.		9	2	4		2	1			
B. S. and Water Undiff.			2	1			1	1	3	3

Three methods of dehydration of this oil are used at West Columbia. The method of boiling or steaming is still used to some extent. The cost of this process for West Columbia is not at hand, but according to the Oil Weekly, several companies on the Gulf Coast have estimated their costs at 15 to 20 cents per barrel. From which field or fields these figures have been obtained is not stated. These figures do not allow for the losses during treatment of the more volatile constituents. The electric method of separation has been tried at West Columbia, by the Crown O. & R. Co. and by the Humble O. & R. Co. The Crown O. & R. Co. has a six unit Cottrell type plant. The electric method of separation is said not to have been very successful and has been abandoned by the Humble O. & R. Co. in favor of the "Tret-O-Lite" chemical process. In this process

[11]Data that given by the "Oil Weekly" and the "Oil & Gas Journal."

the patented chemical is sucked into the line by the pump picking up the oil and the water settles out at the tanks and is there bled off. A barrel of the chemical is sufficient to dehydrate 10,000 to 15,000 barrels of the West Columbia emulsion. This process is used by both the Humble Oil & Refining Co. and The Texas Co. at West Columbia and has proved most successful. It gives a water content of 1%, which is 1% below the maximum allowed by the pipe line companies. The cost of this method of dehydrating at West Columbia is between 1 and 2 cents per barrel.

There are at present three pipe lines into West Columbia. The Texas Company has one 8-inch line to a loading rack at Damon Mound and an 8-inch line to the Houston ship channel. The Humble O. & R. Co. has an 8-inch line to Webster on its main Texas City line. The Texas Company is now duplicating its line to Houston. There is also a loading rack on the I. & G. N. R. R.at East Columbia.

During 1919, the price of the oil was $0.75 a barrel. During the greater part of 1920 the price was $3.00 a barrel. During the Fall of 1920 the bids by the pipe line companies for oil for earthen storage were reduced to $2.00. Late in the year the price of the crude was cut to $2.50 and at the first of the year it was cut to $2.00.

GEOLOGY OF THE CAT CREEK OIL FIELD, FERGUS AND GARFIELD COUNTIES, MONTANA

BY CHARLES T. LUPTON AND WALLACE LEE

INTRODUCTION

HISTORY AND GENERAL STATEMENT

The Cat Creek field was the most promising oil field opened in the United States during the year 1919, and is the first one opened entirely within Montana. It was examined in a reconnoissance way for coal by C. F. Bowen, of the U. S. Geological Survey during the summer of 1912, but was not considered of sufficient importance as an oil possibility at that time to warrant an oil report or its withdrawal. The U. S. Geological Survey coal report[1] includes a map showing the extreme western part of the Cat Creek anticline. It was the V-shaped outcrop of the Eagle sandstone opening to the east shown on this map that led the senior author of this paper to visit the locality in February, 1919. After spending less than two days in examing the major structure, which is about twenty miles long and eight miles wide at the widest place as shown on the accompanying map (Plate I), he recommended the structure and urged immediate action. Montana, however, was considered hopeless as an oil producer by most oil operators in the Rocky Mountain region and no action was taken at that time. Later, in the summer of 1919, The Frantz Corporation was formed and practically the entire anticline was leased or located. While this was being done detailed geologic work was begun by the junior author and L. R. Van Burgh. Only part of the detailed mapping of the major structure was completed in 1919, but sufficient was done to ascertain the presence of at least three minor anticlines and domes on the major structure, and to locate the highest point structurally near which the first test well was located. The discovery well was spudded in in Decem-

[1]Bowen, C. F., Coal discovered in a reconnoissance survey between Musselshell and Judith, Montana, U. S. Geol. Survey Bull. 541-H, pp 39-47, 1914.

ber, 1919 and oil encountered in the third sand of the Kootenai formation on February 19, 1920.

The remainder of the major structure was mapped in detail during the summer of 1920. The six minor domes developed by this and the earlier work are shown on the accompanying map. In October, 1919, the U. S. Geological Survey published a report and map by Bowen[2] in which the position of the outcrops of the Judith river and higher formations in the eastern part of the Cat Creek field and adjacent areas are shown. Bowen in his report recognizes the presence of the Cat Creek anticline but evidently considered its possibilities slight as an oil reservoir.

During the summer of 1920 the U. S. Geological survey made an examination of the Cat Creek field but its report and map of the area have not been published at this date.

The term Cat Creek anticline, as used in this paper applies to the major closed structure on the main Cat Creek axis, where it is crossed by Musselshell river. The Cat Creek anticline proper is shown on Plate I and its relation to the Cat Creek axis is indicated on Plate II which shows the main structural features of the general region.

At the present time a 4-inch pipe line is carrying 2200 barrels of oil daily to the loading racks on the Winnett branch of the Chicago, Milwaukee & St. Paul Railroad at Winnett. To date, February 5, 1921, twenty-three wells have been completed to the first sand on the major Cat Creek anticline. All of the oil produced to date has been derived from the first and third sands of the Kootenai formation, designated from the top downwards.

On the Cat Creek anticline proper four of the six minor structures developed have been tested, and all yield oil in commercial amounts. Of the five light oil bearing sands in the Kootenai formation three have been tested and found to carry oil ranging in gravity from 45° to 51° Beaume. With these

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[2]Bowen, C. F., Gradations from continental to marine conditions of deposition in Central Montana during the Eagle and Judith River epochs, U. S. Geol. Survey, Prof. Paper 125-B, Oct. 20, 1919.

GENERALIZED GEOLOGIC MAP
SHOWING
CAT CREEK OIL FIELD AND ADJACENT STRUCTURE.

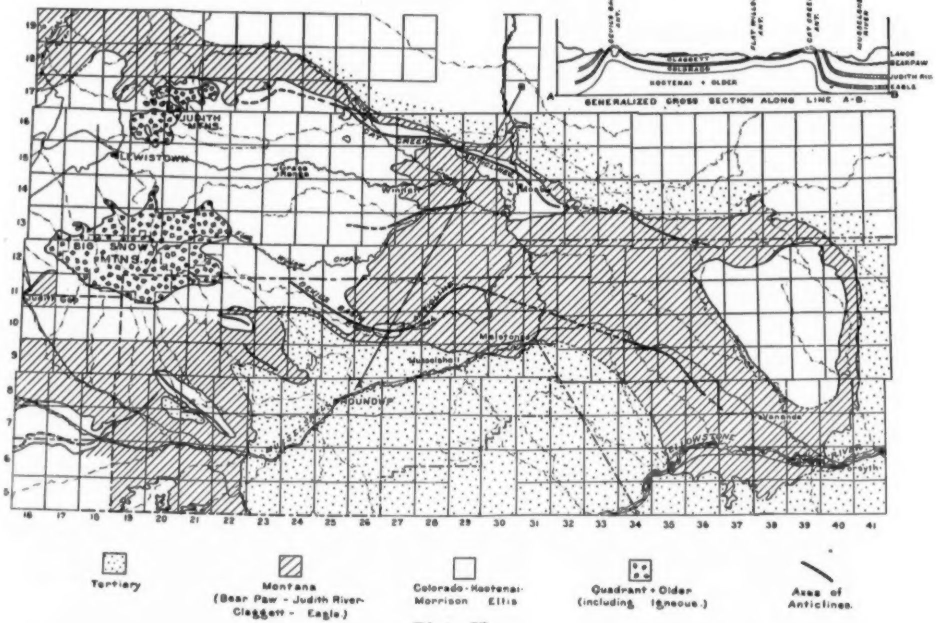


Plate II

conditions it seems reasonable to predict that the field will produce a great deal of oil.

LOCATION AND ACCESSIBILITY

The Cat Creek oil field is situated in Fergus and Garfield counties, in east central Montana. It is included mainly in T. 15 N., Rs. 29 and 30 E., T. 14 N., R. 30 and 31 E. of the Montana Meridian. Winnett, on a branch of the Chicago, Milwaukee & St. Paul Railroad, is the nearest railroad point to the Cat Creek field, it being about 15 miles from the west end of the most productive structure.

The Cat Creek field is also accessible from the main line of the Chicago, Milwaukee & St. Paul Railroad at Melstone, 35 to 40 miles to the south, but the distance is greater and the roads poorer than from Winnett.

SURFACE FEATURES

The surface of the Cat Creek anticline is hilly. The most prominent topographic feature is the valley of Musselshell river, which crosses the structure in a north-south direction. This valley varies from one-fourth mile to one mile in width and is bordered by "bad-land" type of hills for a mile or more from the valley edge. Farther back from the river the surface is smoother and rolling gravel-capped areas are present, except along the larger tributary valleys. Along Musselshell river the altitude of the surface is about 2500 feet above sea level, whereas the maximum elevation on the hills is about 400 feet greater or 2900 feet above sea-level.

The principal stream draining the surface of the structure west of the river is Cat creek from which the structure is named. It is an intermittent stream and empties into the Musselshell near the center of T. 15 N., R. 30 E. Sage Hen creek drains the area east of the river and cuts through the axis of the structure. The lower part of both valleys is bordered by low bluffs, with badlands in the upper part.

CHARACTER OF THE OIL

The gravity of the oil from the first sand of the Kootenai formation is about 51° Baume, whereas that of the oil from the

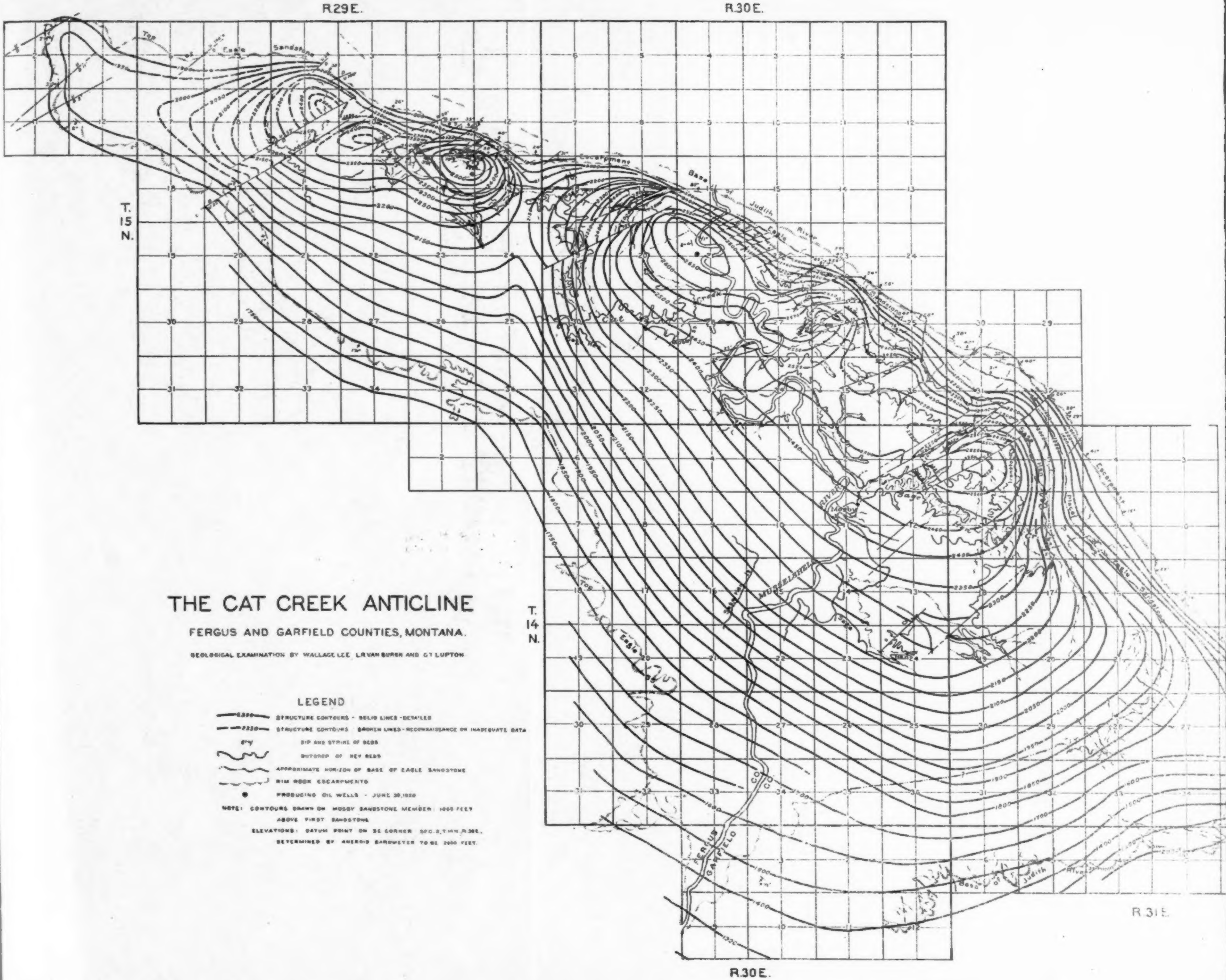
second sand is about 4° less or 47.6°. An analysis of the oil as determined in the laboratory of the Midwest Refining Company at Casper, Wyoming, is as follows:

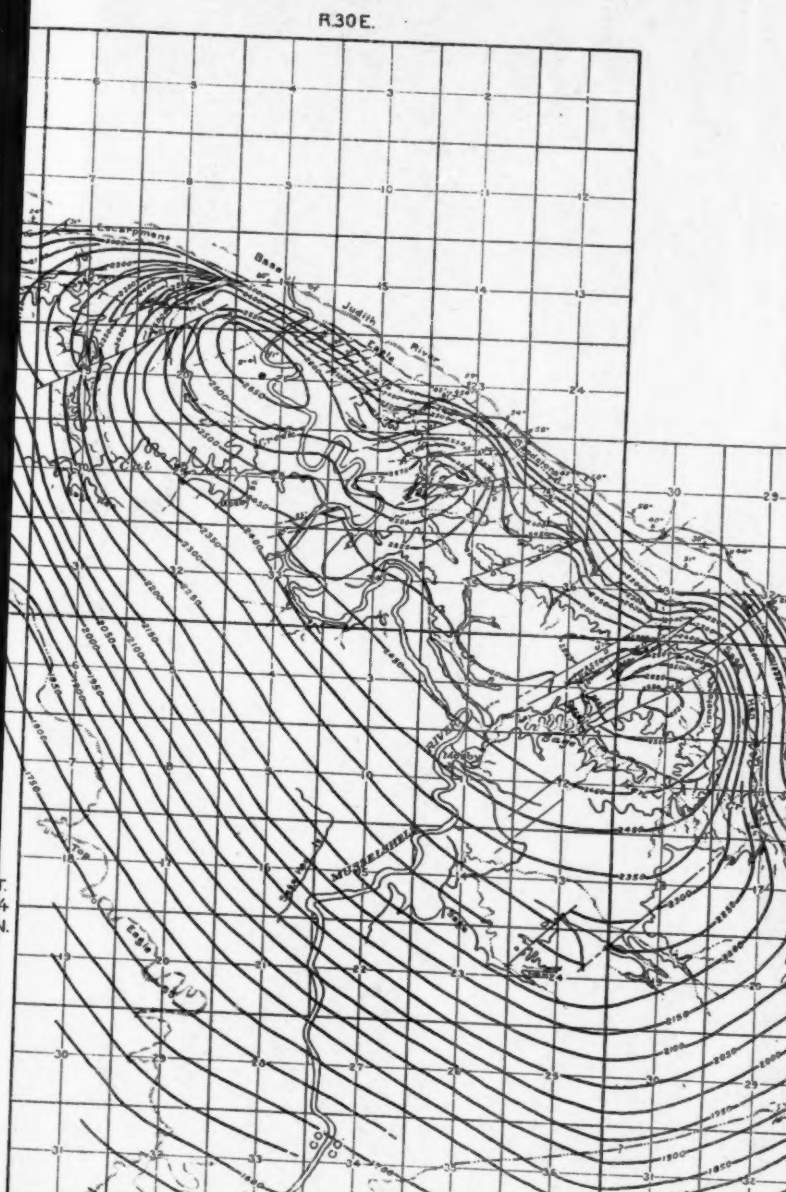
Analysis of Cat Creek Oil

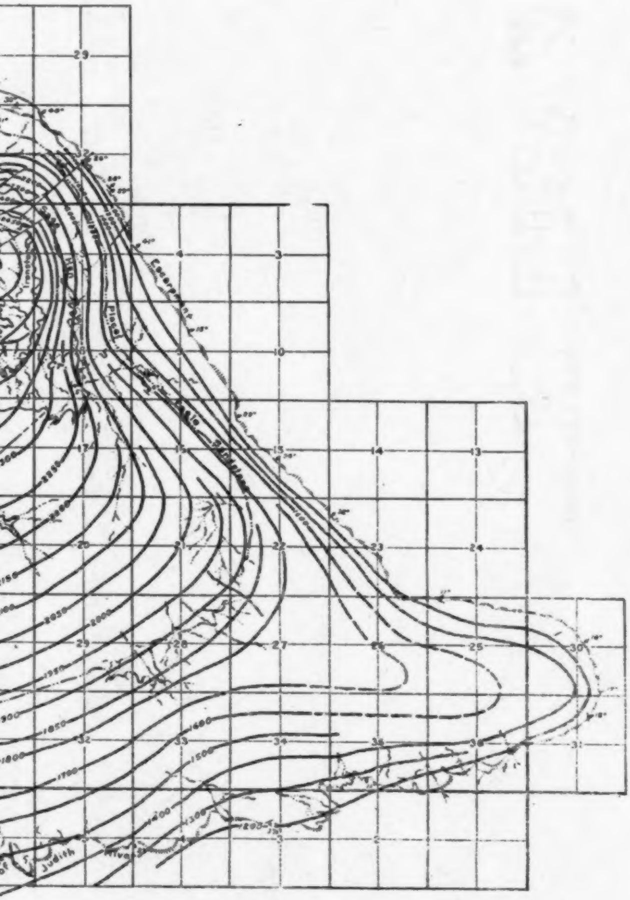
Gravity	47.6 Baume		
Gasoline	56.0 per cent	Gravity	56.8° Baume
		Dry Point	415
W. W. distillate	32.41 per cent	Gravity	42.4° Baume
		Flash	160
		Burn	175
Gas oil	1.56 per cent	Gravity	36.6° Baume
Wax distillate	5.67 per cent	Gravity	32.9° Baume
		Flash	260
		Burn	310
		Viscount	57@100
		Cloud	22
		Pour	15
Fuel residuum	1.72 per cent	Gravity	22° Baume
Residue losses	2.12 per cent		
Sulphur	.8 per cent		
Undetermined	.52 per cent		

The remarkable characters of the oil are the apparent lack of a base and the unusually high percentage of gasoline and kerosene, and the absence of the lighter constituents usually present. In the migration of this oil from its source a double cut seems to have taken place, one cut from the bottom and one from the top. In refining the oil the gasoline content must be mixed with casing head gasoline or cracked to raise the initial boiling point. To date no gas has been found in any of the wells, even those on the crest of the dome.

The first oil was discovered in the Cat Creek field in the third sand of the Kootenai formation, in February, 1920, on the minor structure crossed by Musselshell river, the first sand yielding artesian water and the second, only five feet thick being dry. The next drilling was done on the first minor structure, about 3½ miles to the west, where oil was encountered in the first sand of the Kootenai formation. This well came in in May, 1920 and made on an average 350 barrels daily until about the middle of August, 1920, when after being cleaned out the flow increased to about 2,000 barrels daily. This continued until offset wells were drilled when the daily flow was


R.29E.
R.30E.
T.
15
N.
T.
14
N.
R.31E.
R.30E.
THE CAT CREEK ANTICLINE
FERGUS AND GARFIELD COUNTIES, MONTANA.
GEOLOGICAL EXAMINATION BY WALLACE LEE, L.R.VAN BURGH AND C.T.LUPTON
LEGEND
STRUCTURE CONTOURS - SOLID LINES - DETAILED
STRUCTURE CONTOURS - BROKEN LINES - RECONNAISSANCE OR INADEQUATE DATA
DIP AND STRIKE OF BEDS
OUTCROP OF KEY BEDS
APPROXIMATE HORIZON OF BASE OF EAGLE SANDSTONE
RIM ROCK ESCARPMENTS
PRODUCING OIL WELLS - JUNE 30,1920
NOTE: CONTOURS DRAWN ON MOSBY SANDSTONE MEMBER: 1005 FEET ABOVE FIRST SANDSTONE
ELEVATIONS: DATUM POINT ON SE CORNER SEC.2,T.14N.,R.30E., DETERMINED BY ANEROID BAROMETER TO BE 2500 FEET.


R.30E.
Escarpment
Base
Judith
Eagle
River
MUSSELSHELL
RIVER
Mosby
Top
Eagle
FERGUS
GARFIELD
CO.
CO.
Base of Judith River
R.30E.



R.31E.

reduced to 400 or 500 barrels. The largest well in the field was the offset to the last well referred to which had an initial daily flow of about 2500 barrels when first drilled. It should be stated that practically all of the oil produced to date has come from this dome, three and one-half miles west of the discovery well. The present daily production can be increased by the construction of additional pipe line facilities and by drilling additional wells into the top sand of the Kootenai.

All of the oil produced and marketed from the Cat Creek field to date has come from the uppermost sand of the Kootenai formation, the discovery well having been so completely overshadowed by later developments that the dome on which it is located has been neglected until recently.

PROBABLE SOURCE OF THE OIL

Taking into consideration the high gravity of the Cat Creek oil and its especially high percentage of gasoline and kerosene, the abundant faulting present in Cat Creek field and the increase in gravity downward in successive sands, one is led to the conclusion that the oil found in the upper sands of the Kootenai formation has migrated from some more deep seated reservoir.

Some of the oil in the upper sand of the Kootenai may have migrated downward from the lower part of the Colorado shale, but the most of it, in the writers' opinion, must have come from below. In support of this theory, attention is invited to the fact that very little carbonaceous shale is present in the Kootenai and underlying Morrison formation. In the Ellis formation (equivalent to the Sandance of Wyoming—marine Jurassic) there are some dark marine shales and limestones which could serve as a source of oil. Beneath the Ellis is the Quadrant formation which corresponds to the Embar, Tensleep and Amsden formations of the Wyoming section and in this general region contain local black shale beds which could serve as a source of oil. These formations in Wyoming produce oil of about 25° B. With the numerous faults present in the Cat Creek field, oil from these lower beds could easily migrate upward and saturate beds of sandstone in the Kootenai, whereas the 1900 feet or more of practically unbroken Colorado shale

would serve as a suitable impervious cover. The lighter constituents of the oil would travel farthest, thus giving a very light oil with a high percentage of gasoline in the sands farthest from the source. It appears also that the lightest constituents have escaped, if they were ever present.

STRATIGRAPHY

GENERAL STATEMENT

The lowest formation exposed along the crest of the Cat Creek anticline is the Colorado shale, at the shallowest place 800 feet of this shale being buried. The Eagle sandstone forms a conspicuous rim rock or escarpment on the west side of Musselshell river. East of the river the Eagle grades out rapidly and disappears and the Judith River formation constitutes the rim rock. This rim rock is considerably more conspicuous on the north side where dips are greater than on the more gently dipping south side. Outside the Eagle are concentric exposures of the Claggett shale, Judith River formation and Bearpaw shale of upper Cretaceous age.

The Claggett shale and Eagle sandstone close on the south side of the anticline. On the north side, owing to the unconformable overlying Lance formation, the Bearpaw shale is largely concealed, except along Musselshell river, which has cut through the Lance formation.

Beneath the Colorado shale lies the Kootenai formation believed to be equivalent in part to the Dakota sandstone, and beneath the Kootenai lie in order the Morrison, Ellis and Quadrant formations and the Madison limestone.

MISSISSIPPIAN SYSTEM

Madison Limestone—The Madison limestone is not exposed nearer than the eastern edge of the Big Snowy Mountains, sixty miles from the Cat Creek field. As the Madison limestone at the Big Snowy locality which was examined by Calvert[3] was not studied in detail by him, he refers to the work of Weed[4] in the Little Belt Mountains 40 to 50 miles far-

[3]Calvert, W. R., Geology of the Lewistown Coal field, Montana, U. S. Geol. Survey Bull. No. 390, pp 14, 15, 1909.

[4]Weed, W. H., Little Belt Mountains folio (No. 56), Geologic Atlas U. S. Geol. Survey, 1899.

ther west where the Madison limestone is reported to consist of three divisions with an aggregate of 1000 feet. The lower one-third is grayish, thin bedded, shaly limestone, named the Plaine shale, which is overlain by light colored limestone termed the Woodhurst. The upper part of the Madison limestone is a very massive member designated the Castle limestone.

PENNSYLVANIAN (?) SYSTEM

Quadrant formation—The Quadrant formation is the approximate equivalent of the Embar, Tensleep and Amsden formations of the Wyoming section. The small amount of very heavy oil found in the Devil's Basin wells north of Roundup is believed to have been encountered in some of the beds of the Quadrant formation.

The Quadrant consists of shale, limestone and sandstone, and varies in thickness in different localities. On the north side of the Little Belt Mountains, Calvert[5] reports 425 feet of Quadrant, but on the south side of the same mountains he reports the Quadrant to be 747 feet thick. The authors are indebted to Dr. H. B. Patton[6] for the following careful sections measured by him on the east slope of the Big Snowy Mountains, some 45 miles from the Cat Creek field:

Section of Quadrant formation in the Big Snowy Mountains

Quadrant formation	*Feet*
Limestone, gray, beds 6 inches to 3 feet, carries *Productus*	108
Shale, covered gray	87
Sandstone, dark red and red shaly sandstone	188
Sandstone, white hard	39
Sandstone and shales, red, conglomeratic at top, black to gray shales at bottom	143
Limestone, compact, dark gray, 2 inch bed black chert	2
Shale, gray with thin bed black limestone (a possible fault here which might make this too thick)	346
Limestone, gray limy shale and shale	29
Limestone, compact, weathers white	2
Shale, soft, greenish gray	2
Sandstone and shale, gray	80
Sandstone, light gray	13

[5]Calvert, W. R., Loc. cit. pp 15-19.
[6]From unpublished notes with permission.

Quadrant formation—(Continued)

Shale covered	58
Sandstone, light gray, fine grained	11
Sandstone, soft, dark brown	10
Gypsum, white	10
Sandstone, yellow, soft	12
Shale, gray	3
Sandy shale, red, possibly red soft sandstone, some gypsum	150
Total	1293

JURASSIC SYSTEM

Ellis Formation—The Ellis formation of marine Jurassic age is believed to be the equivalent of the Sundance formation of Wyoming and South Dakota. It is variable in thickness in this region and rests unconformably on the underlying Quadrant formation. No section of the formation was measured by the writers. Calvert[7] measured a section on the east fork of Big Spring creek in section 2. T. 14 N., R. 19 E. several miles southeast of Lewistown and 70 to 80 miles from the Cat Creek field. His section of the Ellis formation follows:

Section of Ellis Formation on bluff of East Fork of Big Spring Creek

Morrison formation	*Feet*
Partly concealed: lowest 30 feet sandy soil, sprinkled thickly with *Gryphea calceola*, underlain by a ledge of sandstone with abundant oyster shells; lowest 20 feet is sandstone also filled with oyster-shell fragments	100
Sandstone, compact, blocky, gray, weathering tan; upper 15 feet forming bold cliff; fossiliferous at top, but shells mostly fragmentary	48
Concealed, grassy slope with red soil	80
Limestone, shaly at bottom becoming thinly bedded, dove-colored, fossiliferous	10
Shale, red, sandy	4
Gypsum white and pure	20
Shale, dark, fissile and gypsiferous	5
Limestone, fossiliferous	3
Partly concealed but containing gypsiferous shale	45
Gypsum and shale	5
Party concealed slope of dark soil	42
Total	362

[7]Calvert, W. R., Loc. cit. p 20.

The fossiliferous beds of this formation may have served as a source for some of the oil found in the Cat Creek field.

Morrison Formation—The Morrison formation consists of fresh water shales and dense argillaceous limestones of light colors. It is about 150 feet thick east of Lewistown. Calvert[8] makes the following statement relative to the age of the Morrison in this general locality:

> The question of the age of the Morrison has been a cause for considerable controversy, and the formation has been assigned to both Jurassic and Cretaceous. Such evidence as has been furnished by vertebrate fauna in the Great Falls and Lewistown fields, however, seems to be in favor of the assignment of the Morrison to the Jurassic, and it is so considered in this report, although the question is one upon which the last word has probably not yet been said.

CRETACEOUS SYSTEM

Lower Cretaceous

Kootenai Formation—The Kootenai formation is the oil producing formation in the Cat Creek field at the present time. It is limited above by the Colorado shale and below by the Morrison formation. It consists of about 500 feet of varicolored shale, sandstone and limestone along the east base of the Big Snowy Mountains 50 to 60 miles from the Cat Creek field, the nearest exposure to the productive area. Calvert[9] and Fisher[10] in the areas around Lewistown and Great Falls include the top sandstone of the Kootenai formation, as defined in this report, in the Colorado shale. In the writers' opinion the Kootenai formation of Montana is the approximate equivalent of the Cloverly formation of Big Horn Basin, Wyoming. The Cloverly, as pointed out by Darton[11] is the probable equivalent of the Dakota sandstone, Fuson shale and Lakota sandstone of the Black Hills section. Therefore, if the Kootenai is the equivalent of the Cloverly, the equivalent of the Dakota, represented in the Cloverly, should be present at the top of the Kootenai in

[8]Loc. cit. p. 24.

[9]Calvert, W. R., Ibid. p. 30.

[10]Fisher, Cassius A., Geology and Water resources of the Great Falls Region, Montana, U. S Geological Survey Water Supply Paper No. 221. pp. 15 and 22, 1909.

[11]Darton, N. H., Geology of the Bighorn Mountains, U. S. Geological Survey, Prof. Paper No. 51, p. 53, 1906.

the Montana section. For this reason, the writers have included the sandstone at the base of Calvert's and Fisher's Colorado shale in the top of the Kootenai formation, and believe it to be the approximate equivalent of the Dakota. Kootenai formation at the top of a prominent sandstone which in the writers' opinion is the same sandstone that Calvert and Fisher included in the lower part of the Colorado shale. The Vananda well is about forty-five miles from the Cat Creek field, whereas the areas examined by Calvert and Fisher are from 80 to 200 miles distant from the Cat creek field.

The Kootenai formation, as stated above, consists of about 500 feet of varicolored shale, sandstone, limestone and a little coal in places. The following section compiled from well logs in and adjacent to the Cat Creek field show the general characteristics of the Kootenai formation:

Section of the Kootenai formation compiled from logs of wells drilled in and adjacent to the Cat Creek field, Montana

Kootenai formation	*Feet*
Sand, light (1)	35
Shale, light	25
Red slate	5
Sand (2)	5
Red shale	15
Light shale	10
Red shale	35
Dark shale	8
Red shale	57
Black shale	5
Sand (3)	15
Shale	5
Sandstone, limy at top	14
Shale, variegated with a few thin sands	60
Sand (4)	140
Gray, red and brown shale	60
Sand (5)	15
Total	509

The sand numbered (1) in the above section is the one producing practically all of the oil now being run from the Cat Creek field. In the discovery well in sec. 21, T. 15 N., R. 30 E. this sand carried a large flow of fresh artesian water.

The sand numbered (3) yielded oil in the discovery well.

The sand numbered (4) carries water in section 21 and 27, T. 15 N. R. 30 E, but is reported to be productive in a well recently drilled in the NE¼ of NW¼ of Section 15, T. 15 N. R. 29 E.

The sand numbered (5) has not been tested at any place in the Cat Creek field.

Upper Cretaceous

Colorado Shale—The lowest rocks exposed at the surface in the Cat Creek field proper are of Colorado age. This formation has a thickness determined from well logs and measured sections of 1924 feet exclusive of the sandstone at the base, considered by some geologists as of Colorado age but not regarded as such in this paper. It consists predominantly of dark and black shales with some thin sandstone members near the middle of the formation, and in the middle and upper parts some beds which are quite limey though there are no true limestones, the lime being usually in secondary concretions or limey clay bands. In general, the sandy beds increase in number and thickness toward the west while the limey character of the upper part decreases in the same direction.

The lower limit of the formation is considered to be at the top of the productive sand at the top of the Kootenai; the upper limit is at the base of the Eagle. Several distinct and easily recognized datum planes occur in the exposed part of the formation in the region of Musselshell river. The lowest of these, called the Mosby sandtsone, from Mosby post office, is 1065 feet above the base of the formation. It is from 3 to 4 feet in thickness and divided into two approximately equal parts by a dirty fossiliferous limestone bed about 6 inches thick. Along the Musselshell it forms a conspicuous rim rock at the top of the bluffs bordering the river, and has a uniform and unvarying character. Farther west in the Box Elder dome, T. 15 N., R. 26 E. what is probably the equivalent of the Mosby member has been observed. It is somewhat thicker, although less conspicuous, due to the absence of the lime which characterizes it on Musselshell river. A somewhat similar but non-calcareous

bed two feet thick, usually less conspicuous, occurs seventeen feet above the Mosby member on Musselshell river and at some localities closely resembles it.

The Sage Hen sandy limestone is 335 feet above the Mosby member. It is named from conspicuous exposures in Sage Hen creek. It has a maximum thickness of about 20 inches in section 8, T. 14 N., R. 31 E., and consists of a fine grained sandstone, cemented with the lime and when fresh shows no indication of its sandy character. When weathered the bed becomes rotten and can be crumbled with the fingers and where much weathered is inconspicuous. It thins to about one foot in section 10, T. 15 N., R. 29 E., and near the Ohio well, section 35, T. 16 N., R. 27 E., it has a thickness of less than 10 inches, At this point the sandy constituent has become both less in thickness and finer in grain, so that the characteristic crumbly weathered surface is no longer striking. It occurs at the top of a zone of calcareous concretions about 130 feet thick. These concretions are embedded in shale containing a considerable proportion of thin very finely banded sandstone laminae which are one-eighth or less to 3 or 4 inches in thickness. This zone is believed to represent in part the Frontier formation of other areas and the Sage Hen member marks its top.

Above this member there is a distinct change in sedimentation. The beds overlying it are conspicuously argillaceous and ascending in the section become somewhat calcareous, though there are no limey beds in the first 200 feet. The lime is present in secondary replacements at the contact of the more impervious shale layers and in indefinite ragged concretions, some of which are sparsely fossiliferous. Discontinuous bands of cone in cone gypsum are common in this part of the formation.

The top of the Colorado is at the base of the Eagle sandstone west of Musselshell river, but east of the river the Eagle sandstone grades into shale and it is no longer possible to determine the line of contact. There is, however, near the base of the Eagle a bed of whitish clay about 1½ feet thick, which weathers into a striking white band littering the surface with yellowish ivory colored chips which are probably aragonite.

This bed can be traced in the lower part of the Eagle sandstone both east and west of the river. East of the river it extends far beyond the eastern limit of the sand. Although it is a little above the base of the formation it serves as a convenient point for mapping the top of the Colorado. This bed was called the "ivory band" and differs from similar beds observed lower in the section only by the peculiar yellowish ivory color of the aragonite chips which accompany the weathered bed.

Several other datum planes of importance should be mentioned. The "ironstone zone", occurring 110 feet above the Mosby, consists of a group of four or more thin bands of clay ironstone from 1 to 3 inches thick, separated by black shale. This zone is conspicuously free from tree growth and is in striking contrast to the blue gray shales below it which on the Musselshell support an abundant growth of cedar, and the concretionary zone above, upon which grow mixed cedar and pine. This ironstone zone can be identified at least as far west as Lewistown. The concretionary zone mentioned has already been described in discussing the Sage Hen member. It is much thinner to the west and north of Grass range, where it does not exceed 50 feet in thickness, although on Musselshell river the zone is at least 13 feet thick. The Mowry shale, so conspicuous throughout Wyoming and central Montana is absent on Musselshell river. It is recognizable, however, near Lewistown, and about three miles north of Grass range it has a thickness of slightly over 10 feet and contains some sandy layers also crowded with fish scales. It thins eastward and near the Ohio well in section 35, T. 16 N., R. 27 E., its thickness does not exceed 15 or 20 feet. A careful search failed to reveal any extension of this member in the outcrops bordering Musselshell river. Its position near Wild Horse lake and in T. 16 N., R. 26 E., is between the ironstone zone and the concretionary zone.

The following is a composite section of the Colorado made from well logs and sections measured at the surface:

Composite Section of the Colorado Shale

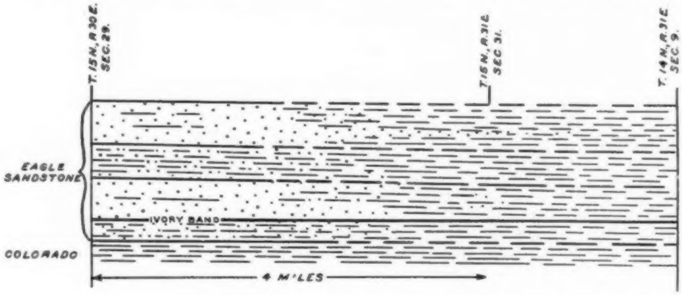
	Feet
White clay "ivory band"	1½
Shale	55
White clay band	½
Shale	80
Shale with light colored soft ironstone bands	13
Shale, light	137
Shale, black	49
Shale, with concretions and cone in cone bands	101
Shale	47
Soft sandstone bed, with thick aragonite crusts	1
Shale	64
Sage Hen member	
Limey sandstone, weathering to soft light colored sandy concretions	1
Concretion zone, dark, shaly, in part finely sandy with flattish septarions 2-5 ft in diameter and 1-2 ft. thick, filling of brown calcite	131
Band of yellow concretions	2
Shale, dark (place of Mowry not present on Musselshell river)	61
Ironstone zone, 3-4 bands hard brown ironstone 2-3 inches thick in dark shale, no tree growth	15
Shale, blue, cedar growth	41
Blackish sand banded with yellow clay	4
Shale, sandy partings	33
Sandstone, soft	2
Shale, dark sandy partings	17
Mosby sandstone member.	
Sandstone 1-2 inch thick at top and bottom with fossiliferous limestone parting 6 inches thick in center	3
Shale black, some fine sandy partings, yellowish clay bands and bentonite. Roundish concretions near middle	200
Shale, (well log)	865
Total	1924

Eagle Sandstone—The Eagle sandstone consists of three members, an upper and lower sandstone, separated by sandy shale. The upper member is usually light colored to whitish, evenly bedded and in part thinly laminated, although locally the bedding is irregular and the sand dirty.

The lower member is in most cases irregularly bedded, yellowish gray in color and somewhat argillaceous. Both upper and lower members are in general but not always conspicuous

where present, the upper usually being the thicker. Fifteen feet above the base of the lower sandstone the white clay bed with the ivory colored aragonite chips forms a well marked band traceable throughout the field. The evidence furnished by this bed and the upper member of the Eagle, which is more persistent to the east than the basal member, indicates very clearly that the Eagle disappears by grading laterally into the sandy shale and shale by insensible but rapid gradation.

In the northwest quarter of Township 14 North, Range 31



SKETCH SHOWING
EASTWARD GRADATION OF EAGLE SANDSTONE
Figure I

East, the ivory band already described occurs at intervals of 90 to 110 feet below the thin eastward extension of the upper sandstone member, indicating that the conditions are those suggested in the accompanying sketch, (Fig. I) and that the Eagle does not, as has heretofore been stated[12], thin out to a knife edge as a separate unit.

There are only about four or five miles between the point where the Eagle is present at its full thickness and the point where the Eagle is entirely missing as a sandstone formation. The Eagle has a thickness of 149 feet in section 32, Township 14 North, Range 39 East. The apparent thickness of the formation is to some extent dependent upon the weathering and local variations in the sand content. Where case hardening has not occurred the dirty sandstone at the base weathers to an

[12]Bowen, C. F., Possibilities of oil in the Porcupine Dome, Rosebud County, Montana, U. S. Geol. Survey Bull. No. 621-F. p. 64, 1915.

inconspicuous shaly slope, usually not distinguishable as Eagle.

Claggett Formation—The Claggett formation lies immediately above the Eagle. It is about 900 feet thick. The basal part consists of shales, with a number of bentonite beds. There are also some concretions of shaly lime and some thin sandy limestone beds near the middle. The upper part is chiefly flaky, almost paperlike shale with occasional sandy limestone concretions.

Judith River Formation—The Judith River formation overlies the Claggett conformably and consists of three members, which like the Eagle comprise an upper and lower sandstone member. The middle member is the most striking and distinctive lithologic characteristic of the formation. It is composed of banded light and dark colored shales, clays and thin sandstone beds with several ironstone bands and locally some coaly beds of no importance in this area. In outcrops it forms a bench or a saddle between the two outcropping sandstone escarpments. The thickness of the formation in this area is 250 to 350 feet. It forms a bold steeply dipping escarpment on the northeast and south sides of the anticline, but does not close to the southwest.

Bearaw Formation—The Bearpaw formation consists essentially of black shale. The basal 200 feet contain several bentonite beds and some concretions and closely resemble the lower part of the Claggett. There are also, about 150 feet above the base of the formation, some thin medium-grained sands beds, which may be a local development. The upper part weathers to bare, rolling, clay surfaces nearly barren of vegetation with locally intermittent bands of fossiliferous concretions. The upper part contains no sandstone in this part of Montana. The Bearpaw is overlain unconformably by the Lance formation of Tertiary age and its thickness is in consequence variable. It has a thickness in this part of Montana of 1000 to 1500 feet.

TERTIARY

Lance Formation—North of the Cat Creek anticline the ridges are capped with Lance beds. They consist chiefly of gray to yellowish sandy clay, sandstone and some thin

coal beds or carbonaceous clay of no economic value.

STRUCTURE

The Cat Creek axis in the larger sense is one of a group of anticlinal axes, at least two of which extend from the Big Snowy and Judith mountains eastward to the Porcupine dome, a distance of some hundred miles. This group of anticlines was called by Bowen[13] the "Big Snowy anticline," though it is really an anticlinorium containing a series of more or less nearly parallel anticlines, the best known of which are shown on the accompanying sketch. (Plate II.) It is probable that if the intervening Tertiary areas could be stripped away this folding would be found to be on a continuation of the Black Hills axis which extends also southward into Kansas.

The Judith mountains are an isolated mountain group, consisting of steeply tilted Paleozoic rocks with large masses of intruded igneous rocks. The Snowy mountains to the south are an entirely similar mass of tilted Paleozoics, concerning which practically nothing has been written but which is reported by those who have examined it to contain no igneous intrusions. It seems plausible, however, to conclude from its relations and structure that the Big Snowies have also resulted from the intrusion of a laccolithic mass but more deeply buried than in the Judith mountains.

The northern side of the Big Snowy anticlinorium is in alignment with the north side of the Judith mountains, while the southern side is in alignment approximately with the south side of Big Snowy uplift. The external dips are abrupt and sharp while anticlinal dips within the block rarely exceed 3 degrees. It has the appearance especially at the western end of a previously folded area which has been lifted from below along the external anticlines. The external dips are greatest at the end toward the Big Snowly-Judith mountains uplift and are low on the flanks of the Porcupine dome.

A partial explanation of the peculiarities of the regional structure might include a primary gentle folding of strata along the Black Hills axis. The intrusion of laccoliths in the Big Snowy-Judith mountains area with a consequent ten-

[13]Bowen, C. F., The stratigraphy of the Montana Group, U. S. Geol. Survey Prof. Paper 91-I, Plate X and pp. 103, 104, 1915.

dency toward shortening the axis of the anticlinorium, accompanied by an upward thrust on the segment especially at the end toward the mountains.

The term "Cat Creek anticline," the most northerly of the folds in the anticlinorium, was first used by Bowen[14] to designate the western end of the long anticline, which has since been found to extend from the Judith mountains to the Porcupine dome. The term has also been used to designate a secondary structure lying on the axis and in the vicinity of Musselshell river. The double use of the term as it is now established is to be regretted. In this paper unless otherwise specified its use will be confined to the minor structure.

The structures in this region are of three orders of magnitude; first, the long regional anticlines of which Bowen's Cat Creek anticline is a type. On this axis, as well as on others there are a number of minor sub-divisions, distinctly closed anticlines from 5 to 20 miles long—to which various names have been given, as Wild Horse dome, Box Elder dome, Brush Creek anticline and Cat Creek anticline. On these anticlines of the second order, really sub-divisions of the main structure, are smaller and less conspicuous domes from one-half to two miles in diameter.

The axis of the Cat Creek anticline, using the term in a restricted sense, strikes in a general northwest-southeast direction, the general strike of the axis changing from N. 45° W. on the east side of Musselshell river to approximately N 75° W. west of the river, which crosses the structure near the middle. Examined in detail, however, the axis has a strikingly sinuous course changing its direction from 20 to 30 degrees in passing from one minor dome to the next. The highest dips of the structure are on the north side, the maximum being in the center on Musselshell river, where the dip is 80° N. 15° E. From this point the dips diminish both to the west and the east, and near the saddles which separate this structure from adjacent anticlines those toward the north do not exceed 15°. On the south limb of the fold the dip averages 2½° with only slight variations.

[14] Loc. cit.

The central part of the anticline is much affected by faults having displacements of 5 to 100 feet. While some of the faults have a throw greater than 100 feet, most of them have less than 25 feet and very few extend more than one-half a mile laterally, although there are a few notable exceptions as may be seen on the map. These faults are chiefly confined to the crest of the anticline, but there are a few minor displacements on both limbs of the arch. Unfortunately, the weathering and the character of the strata (chiefly shale) usually prevent the exposure of the actual fault planes, so that in only a few cases was it possible to determine whether the faults are reverse or normal. In the few cases observed the fault plane is nearly vertical but the faults appear to be of the thrust type. It is believed from the similarity in strike and arrangement that practically all the faults are of the same type. The faults are chiefly indicated by displacement of datum planes along the outcrop and are characterized in nearly every case by slickensided calcite filling, found usually as float. There is a rather remarkable approach to parallelism of the faults. Without exception they strike to the northeast, and the deviation from N. 55° E. is less than 15° in either direction. No strike faults were observed, all the faults cutting diagonally across the strike of the beds.

The most strikingly faulted areas occur at localities where there is a change in direction of strike of the axis, in a few cases represented by a distinct offset in the crest. This would seem to indicate conclusively that the movement along the faults was not entirely a vertical movement but that the displacements had at least a considerable lateral component also, the crest of the fold having been shifted along the faults to accommodate the strains incident to the change in strike. Practically, none of the faults noted in the central part of the dome cut the scarp of the Eagle or Judith River formations, although there are a few instances of minor character where this is the case.

The total deformation of the anticline is over 3,000 feet at the central point on Musselshell river and the closure is 1200 to 1500 feet. If it is to be assumed that the oil has migrated a

considerable distance, as most geologists are inclined to believe, the main gathering area for oil is to the north where the strata, after the steep dips directly north of the axis, dip gently (2°-15°) northward from 30 to 40 miles. To the south the gathering area is only 10 or 12 miles.

Of the six domes on the anticline, that in section 21, T. 15 N., R. 30, E. is the highest. The crest lies on the flood plain of the Musselshell river, where there are no outcrops. On this account details of the central part are lacking, and in consequence this dome appears to be less affected by faulting than some of the others, although in view of the absence of exposures in this locality this cannot be positively asserted. This dome has a closure of about 125 feet.

To the southeast in the NW¼ of section 26, T. 15 N., R. 30 E. is another dome. This dome is much broken by an intricate set of minor faults, cutting the crest of the structure, forming a number of faulted blocks. None of these faults has a displacement exceeding 60 feet and all die out laterally within comparatively short distances, none of the faults cutting the horizon of the Sage Hen less than one-half mile to the northeast. A low saddle separates this dome from the one in section 21. The closure is about 100 feet, the high point being in one of the faulted blocks. On the southeast side this dome is separated from another and larger dome by a flattish saddle about two miles long and 50 feet lower than the saddle on the northwest side.

The crest of this dome is in the center of section 6, T. 14 N., R. 31 E. at an elevation of about 2560 feet on the Mosby sandstone. The northwest side of this dome is cut by a series of nearly parallel faults resulting in a series of tilted blocks, high toward the crest of the dome and dipping toward the saddle to the northwest. The elevation attained at the crest of the dome is also attained on two of the faulted blocks within one-half mile to the northwest. While these faults extend a distance of one to one and a half miles none cuts the Eagle sandstone to the north. The maximum displacement is about 65 feet. The closure of this dome is only 5 feet.

The three domes just described considered collectively lie on

a raised portion of the anticline above whose closing contours the crests are 525, 500 and 400 feet respectively.

The crest of the so-called "West dome" is in the NE¼ of section 14, T. 15 N., R. 29 E. The dips, except on the north side, are steeper on this dome than on those farther east and the crest is sharper. The north flank is cut by a series of northeast striking faults which cut nearly to the crest but do not cross it. The highest part of the dome is 85 feet lower than the crest of the dome in section 21, T. 15 N., R. 30 E. The dips on the north limb of this dome are from 38° to 40° immediately north of the central part which lies within 200 feet of a fault having a maximum displacement of 150 feet. This fault dies out rapidly, passing into a sharp northwestward dip on the west side and thence into the smooth contours of the dome.

No faults actually cut either the crest or the southern limb of the dome itself. It is closed on the west, however, by a series of faults crossing the axis and having an upward throw to the west. The closure east of these faults is about 200 feet.

The small dome, or perhaps it should better be described as a domed faulted block, occurs in section 10, T. 15 N., R. 29 E. The structure of this block is genetically a part of the west dome lifted up on the east side by a fault and bounded on the west side also by a fault. It has a closure within the fault of about 50 feet being higher on the east side than on the west

Another dome of the same character occurs in the NE¼ of section 9. This dome is separated from the last mentioned by a down faulted block about one-fourth of a mile wide, showing synclinal structure transverse to the axis, which is, therefore, essentially a syncline accentuated by faults. The outcrops are inadequate for a detailed study of this western dome, but it is inferred from the outcrop observed and from the physiography that it has a closure of about 200 feet.

The last three domes mentioned occur on a raised portion of the anticline and rise respectively 400, 300 and 350 feet above the closing contour.

SUMMARY

The Cat Creek field is the biggest oil discovery in 1920 and is the first producing field situated entirely in Montana.

It is situated in Garfield and Fergus counties in the east central part of the state. It is crossed near its middle by Musselshell river.

The surface is hilly with "badland" types of topography in the uplands adjacent to the river. Along the crest of the main structure, the surface varies in elevation from 2500 to 3000 feet above sea-level.

The oil so far produced from this field varies in gravity from 47.6° Baume in the second sand of the Kootenai to 51° Baume in the first sand of the Kootenai, and has a gasoline content of 56 per cent.

To date the production of about 2200 barrels per day is coming from about 10 wells drilled into the first sand of the Kootenai formation. A 4-inch pipe line connects the production area with Winnett on the C. B. & Q. RR. The oil is shipped to refineries at Cowley and Greybull, Wyoming. The oil (February 5, 1921) brings $2.15 per barrel, and in the field $2.00 per barrel.

The oil found in the first and third sands of the Kootenai formation in the Cat Creek field is believed to be migrated oil, judging from the high gravity of the oil, the high percentage of gasoline, the lack of a definite base, and the absence of beds directly beneath the oil bearing beds which could serve as a source for the oil.

The lowest surface rocks along the crest of the Cat Creek anticline belong to the Colorado shale about 800 feet of the formation being buried. Overlying the Colorado are the Eagl sandstone, Claggett shale, Judith River formation, Bear Paw shale and Lance formation. Beneath the Colorado shale are the Kootenai, Morrison, Ellis and Quadrant formations and Madison limestone. Lower and higher formations than those above mentioned are not described in this paper.

The Cat Creek anticline is on the northern side of the Big Snowy anticlinorium, extending from the Big Snowy and Judith mountains to the Porcupine dome. This anticlinorium is probably an extension of the Black Hills axis.

The Cat Creek axis lies on the northern side of the anticlin-

orium and the Devils Basin axis occupies a similar position on the south.

The structures of this field are of three orders of magnitude, first the long regional anticlines, second, closed subdivisions 5 to 20 miles long on the major axes, and third, subordinate domes $\frac{1}{2}$ to 2 miles long on the secondary structures. These last are the productive domes.

The Cat Creek axis is irregular but strikes on an average N. 75° W. The dips range from 15° to 80° on the northeast side of the Cat Creek anticline proper and vary but little from $2\frac{1}{2}$é on the southwest side.

There are many faults chiefly of less than 25 feet displacement, though a few exceed 100 feet. The faults have an approximate parallelism and vary less than 15° in either direction from N. 55 E. There is a close relation between the faults and changes in direction of the axis and there is evidence that there is a considerable lateral shifting on the faults.

The structure has a maximum deformation at the crest of about 3000 feet and a closure of 100 to 15 feet. There is a possible gathering area toward the north of 30 to 40 miles.

On the major anticline there are six secondary domes.

THE RELATION BETWEEN THE STRUCTURE AND PRODUCTION IN THE SALLYARDS FIELD, KANSAS.

BY WALTER R. BERGER.

The Sallyards oil field is a long narrow pool extending from the SE quarter of sec. 25, T. 25 S., R. 8 E. to sec. 20, T. 26 S., R. 8 E., Greenwood and Butler counties, Kansas.

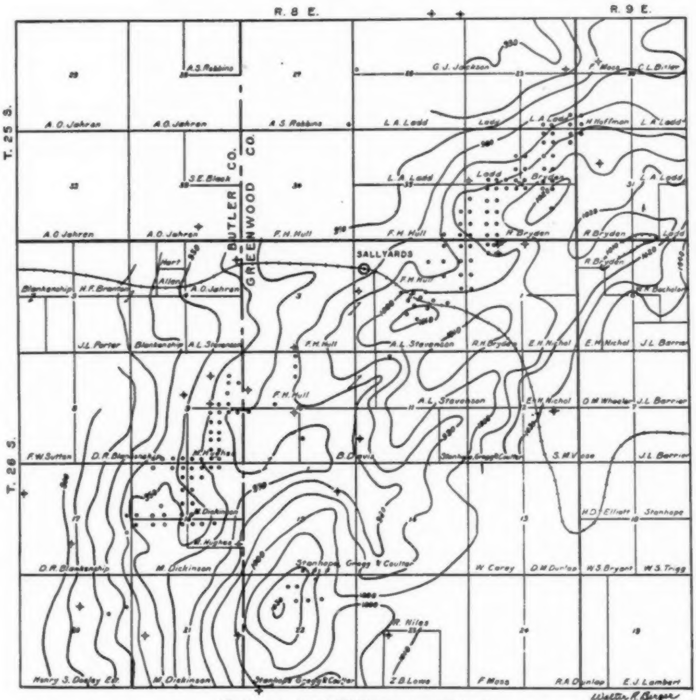
The main producing horizon is a lenticular sand termed the Sallyards or Blankenship sand. This sand, found at a depth of 2300 to 2500 feet, lies about 300 feet below the Fort Scott limestone of Pennsylvanian age, and about 100 to 150 feet above the "Mississippi lime," the equivalent of the Boone chert of Mississippian age. Two other productive horizons occur, one at about 1200 to 1400 feet in sandy portions of the Stanton-Plattsburg-Iola group of limestones. This horizon is only locally productive, the best production being east of the center of sec. 36, T. 25 S., R. 8 E. The other productive horizon is found at a depth of about 2400 feet in a sand which is either a sandy phase of, or a sand on top of the Mississippi lime. This sand is productive in the Stanhope pool in secs. 15 and 22, T. 26 S., R. 8 E.

The surface structure is a double anticlinal fold plunging to the southwest from the SE quarter of sec. 36, T. 25 S., R. 8 E. The two folds spread, the east fold terminating in a dome in secs. 15 and 22, T. 26 S., R. 8 E. The west fold terminates in a very small dome in sec. 16, same township and range. Both lines of folding have small domes in secs. 1 and 2, T. 26 S., R. 8 E. Farther north the structure can only be followed as a flat for a short distance. The east line of folding is more pronounced than the west-line, having greater width and reversal.

The accompanying map of the production and surface structure in the field shows that the production of the Sallyards or Blankenship sand lies principally on the west side of the west line of folding. A few wells in the north part of the field and some of the wells in sec. 16 are on the top of the

west line. A number of dry holes and small wells limit the field extending eastward to the other line of folding. The production of the Stanhope sand, however, is located on the dome found at the south end of the east line of folding.

The second map gives the relation of production to the

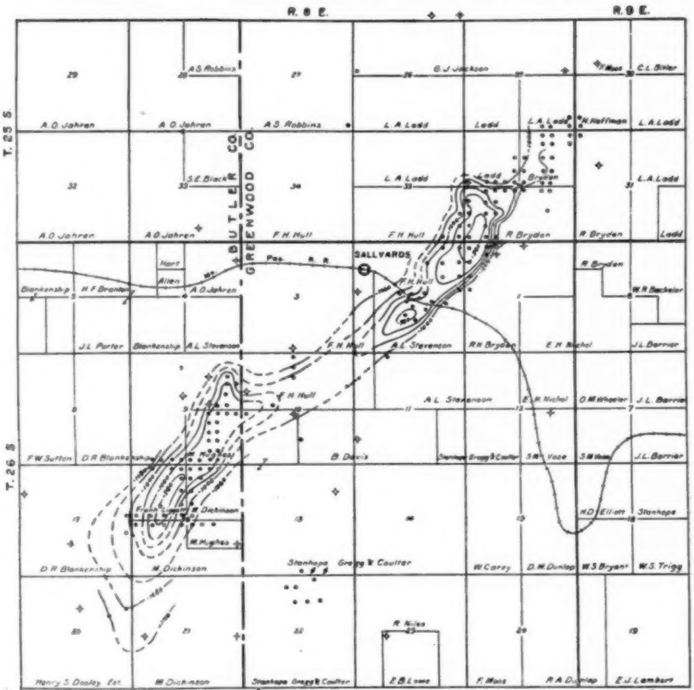


SALLYARDS FIELD
SURFACE STRUCTURE
Contour Interval = 10'
• Rig or drilling well • Oil well ✦ Dry Hole or abandoned well

Figure I

sub-surface structure mapped on the top of the producing sand. An anticlinal fold is shown with two domes, one in secs. 9 and 16, the other in secs. 11 and 2, T. 26 S., R. 8 E. There may be another dome is sec. 36, T. 25 S., R. 8 E., but the well log data in the north end of the field is not reliable

because the top of the sand is very shaly, and drillers evidently report the top of the sand at various horizons. This is also true of the south end of the field in sec. 16. The subsurface structure is much more pronounced than the surface structure. In several places 10 to 15 feet of reversal



SALLYARDS FIELD
SUBSURFACE STRUCTURE
Datum - Top Sallyards Sand Interval - 20'
Rig or drilling well • Oil well ✦ Dry Hole or abandoned well

Figure 2

is shown on the surface while at least 90 feet is shown on the subsurface anticline. The production is closely related both in position and size to the subsurface contours, the production coming from the west side of the surface fold. The best producing wells are located at the top of the several domes.

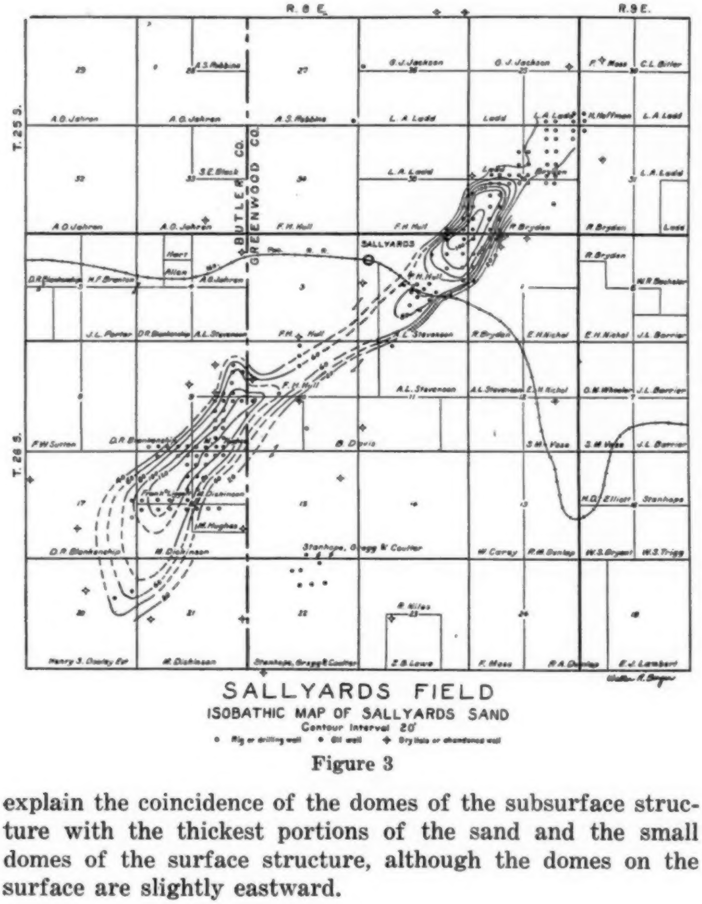
The third map is an isobathic map of the Sallyards sand. It is readily possible to construct such a map as most wells drill practically to the bottom of the sand. The contours compare very well with those on the subsurface map, the wells having the thickest producing sand being found on top of the subsurface domes, and those having the smallest amount on the edge of or off the structure. A remarkable thinning of sand is shown on the east side of the field, in secs. 1 and 2, T. 26 S., R. 8 E., where the sand thins from 150 feet to zero in a quarter of a mile. A number of wells only a short distance from productive wells show but a few feet of sand or none at all.

Conditions such as those present in the Sallyards field could be produced by the following factors. (1) There was a sea, probably of Pennsylvanian age which has as its west boundary the granite ridge of central Kansas and as its east boundary a secondary ridge of which the east line of folding of this structure is a part. This east boundary could have been produced by folding at about the same time as that when the granite ridge was produced, with subsequent differential settling, or by folding at a later time but previous to deposition of the producing sand. The outlet to the sea would be to the south. (2) In a sea of such proportions the shores would be subject to shore and sea currents, which would sort the sediments brought to it by streams from the north and east, and deposit these sediments along the east shore. Such sediments are not expected on the west shore at this time because those shores were undoubtedly exceedingly steep and the water very deep. (3) As the east line of folding is the more pronounced and is higher structurally to the south than to the north, it is likely that almost the same conditions prevailed at the time of deposition of the sand as is now shown by the surface structure. This would permit the sand to be deposited farther from the top of the structural high at the south end than at the north end, where the folding is lower structurally.

The thickness of a sand deposited by currents along shore would vary according to distance from the shore, changes in water level, irregularities in the floor, shore lines and depth

of sea. The thickest portion of the sand, unless other factors arose would be in a zone generally parallel to the shore line, thinning both shoreward and seaward from this zone.

A body of sand of such proportions as the Sallyards sand with shale on all sides of it would be reflected in the sediments above by means of differential settling. This would



SALLYARDS FIELD
ISOBATHIC MAP OF SALLYARDS SAND
Contour Interval 20'

Figure 3

explain the coincidence of the domes of the subsurface structure with the thickest portions of the sand and the small domes of the surface structure, although the domes on the surface are slightly eastward.

This explanation for the presence of the Sallyards sand production on the west side of the west line of folding also explains the present location of the deeper production in the Stanhope sand. If the west line of folding was produced by differential settling of sediments, that folding would not be reflected beneath that horizon. Then the only structure on horizons older than the Sallyards sand would be the east line of folding of the surface structure. The production of the Stanhope sand lies on the dome at the south end of the east line of folding.

The writer wishes to express his thanks to Mr. Everett Carpenter for his interest in the preparation of the paper, and to the Emerald Oil Company for the permission to publish the maps included with this discussion.

NOTES ON GEOLOGY OF THE OKMULGEE DISTRICT

By R. W. Clark and C. Max Bauer.

INTRODUCTION

The Okmulgee district of Oklahoma has figured prominently in the oil industry and oil news for the last year and many companies, through their geologists, have been studying the region and developing new pools and deeper sands. The district comprises all of Okmulgee county and also includes parts of adjoining counties. In gradually increasing amounts, it has produced oil and gas for fifteen years. During the last two years the production has increased from 18,000 barrels to 56,000 barrels per day. In this paper a sketch of the general geology and those phases of the structural geology bearing on the accumulation of oil and gas in the Okmulgee district will be given.

TOPOGRAPHY

The surface in the Okmulgee area consistes of a series of approximately parallel ridges extending in a general northeast and southwest direction. These ridges have very steep eastward facing escarpments with long gentle westward slopes to the base of the next ridge. The escarpments are from 150 to 250 feet high, while the country to the west of them is more gently undulating, with a relief of from 50 to 100 feet.

The principal streams are the North fork of Canadian river and its tributary, the Deep fork. The latter stream flows southeastward about through the middle of the district. Many smaller streams are dry or nearly so except during rainy periods. They have dissected the surface of the district until it presents a good example of maturity of stream erosion.

AREAL GEOLOGY

The surface in the Okmulgee area consists of a series of rock equivalent to the Cherokee shales of the Pennsylvanian farther north. They consist of an alternating series of thick

shale beds and massive sandstones with occasional thin shaly sandstones in the shale members. Small limestone lenses also occur in the shales but only one limestone which is continuous for any distance outcrops in the whole district. The escarpments are due to the massive sandstone members and the areas of more gentle topography are for the most part underlain by shales. Generally the contact between a shale member and the overlying sandstone may be seen distinctly in these escarpments, while the contact between a sandstone and an overlying shale is obscured by alluvium and weathered soil.

The map shows the areal distribution of the formations in the district. The contacts between a shale below and a sandstone above have been mapped by means of a plane table but, from the nature of things, the contacts between sandstone below and shale above can only be approximated. These were sketched in by reconnaissance with the aid of a topographic map. From the top downward the formations which outcrop in the district are:

Geological Formations in the Okmulgee District

Sapulpa group
Tulsa group
Seminole conglomerate
Holdenville shale
Wewoka sandstone
Wetumka shale
Calvin sandstone
Senora formation
Stuart shale
Thurman sandstone
Boggy shale
Winslow formation

The Calvin sandstone underlies the city of Okmulgee. It has been traced continuously from there southward to Canadian river and correlated with the Calvin sandstone of Taff in the Coalgate quadrangle. The other formations are correlated with reference to the Calvin as the key formation. The Checkerboard lime in the Tulsa group can be traced from Deep fork in section 19, T.14 N., R. 11 E., through Mounds and Jenks, over Turkey Mt. and on into Tulsa. It cannot, however, be followed continuously southwestward from Deep

fork though some thin limestones at about that horizon are found in Okfuskee county. The Boggy and Winslow formations are correlated with those of Taff in the Muskogee quadrangle. The writers have not studied these formations in detail and have accepted for them the description and nomen-

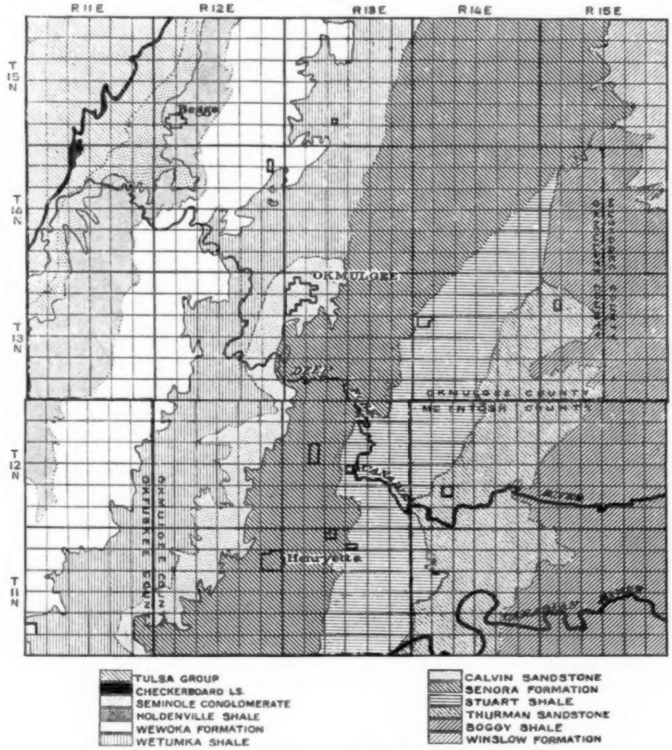


Fig. 1. Geological map of the Okmulgee district.

clature of Taff. In the following descriptions of the formations the Senora, which is the coal-bearing formation of the Henryetta coal fields, is given first. The formations below it are omitted as they are largely outside of the developed territory.

Senora formation.—This formation outcrops in a northeast-

southwest belt through Henryetta, Coalton, Morris and T. 14 N., R. 14 E., and lies at the foot of Bald hill. In the southern part of its outcrop it is a series of sandstone and shale, containing one workable coal bed and several beds of coal too thin to be worked at the present time. To the northeast the sandstones grade into sandy shale and shale and only one bed of coal is known to be present. Its thickness is about 250 feet in the southern part of the area and it diminishes to about 50 feet or less in T. 15 N., R. 15 E., and vicinity.

Calvin sandstone.—This formation is composed almost entirely of sandstone in the southern part of the district but from the center of T. 11 N., R. 12 E., northward it becomes more and more shaly until about two miles northeast of Okmulgee it changes entirely to shale or is cut out by overlap of the Wetumka so that from this point northeastward there is no sandstone. It seems probable that the Calvin is not present here. Its maximum thickness is about 150 feet.

Wetumka shale.—The Wetumka is essentially a shale formation which maintains a thickness of about 120 feet from the southwestern part of the district to the vicinity of sec. 16, T. 14 N., R. 13 E. From this point northeastward it thins considerably but its exact thickness cannot be determined as the formations below it are shale and have the same characteristics as the Wetumka. It contains some short lenses of sandstone.

Wewoka formation.—The Wewoka formation is approximately 50 feet thick throughout the Okmulgee district. It is composed of massive and crossbedded sandstones interbedded with shale and sandy shale in alternating strata of about the same thickness. Its basal bed, as nearly as can be determined, extends for at least 15 miles although it is a thin sandstone having a maximum thickness of but 6 feet. Another sandstone in the middle part of the Wewoka which has been traced for 30 miles, outcrops from the southwest corner of T. 11 N., R. 11 E. northeastward to sec. 3, T. 15 N., R. 13 E. and very probably lies on the top of Conjada Mt. near Arkansas river. The upper portion of the Wewoka formation contains many cross bedded sandstones, which are very difficult to trace and,

where they can be traced, are so irregular that structural data based on them are of little value.

Holdenville shale.—Like the Wetumka, the Holdenville shale contains many thin sandstones, although it is predominantly a shale formation. In the vicinity of Beggs the Holdenville contains also some thin limestone members. At least two of these have been observed but they are only a few inches thick and cannot be traced for any considerable distance. The formation crosses the central part of T. 13 N., R. 11 E. where its average thickness is 180 feet.

Seminole conglomerate.—Overlying the Holdenville is a conglomerate which, in the opinion of the writers, is to be correlated with the Seminole conglomerate of sec. 17, T. 6 N., R. 8 E. as mapped by Taff[1]. This formation has been mapped from the extreme southwest corner of T. 13 N., R. 11 E. to a point in sec. 24, T. 15 N., R. 11 E. about two miles northwest of Beggs. The pebbles in this conglomerate are composed almost entirely of light colored chert. In the western part of T. 13 N., R. 11 E., these pebbles have an average diameter of one eighth of an inch. Northeastward the size of the pebbles diminishes to small grains in the vicinity of Beggs. Beyond this point the bed has not been distinguished from other sandstones in the adjacent part of the section. Its thickness is from 15 to 355 feet, this measurement including the sandstone with which it is associated, the conglomeratic portion of the bed being often much thinner. In some places the conglomerate is at the base, in others at the top and in still others it forms lenses within the sandstone.

Formations above the Seminole-conglomerate.—Above the Seminole in this district is a shale which averages 100 to 120 feet in thickness and belongs to the Tulsa group. This shale is in turn overlain by the Checkerboard limestone. This limestone is remarkable for its persistent character such as thickness, color, resistance to weathering, peculiar fossil markings, jointing, etc. It was mapped in detail along its outcrop from the north side of T. 16 N., R. 12 E., to the southwest corner

[1]Taff, J. A., Geology of the Coalgate quadrangle, U. S. Geol. Survey, Geologic folio 74.

of T. 14 N., R. 11 E., or a distance of about 20 miles. It is a hard blue limestone four feet in average thickness and contains peculiar semicircular markings caused by the presence of fossil brachiopods. Its weathered surface is usually a light cream color or a very light yellow. It breaks into blocks, which are nearly cubical and about four feet on each side. Outcrops are usually found in stream beds and seldom on hills or ridges. A shale belonging to the Tulsa group overlies the Checkerboard limestone and is in turn overlain by the sandstones of the Sapulpa group.

STRUCTURE

Structural features revealed at the surface in the area west and northwest of the outcrop of the Calvin sandstone bear only a slight resemblance to the structures, which are disclosed by subsurface studies. Their significance, however, is important. East of the outcrop of the Calvin the structure of the exposed rocks is believed to correspond more nearly to the structure of the producing sands. There is a general thinning of the formations to the north and northwest and there is considerable evidence of one or more overlaps in the formations belonging to the lower part of the section here described. The stratigraphically highest overlap has been found at the base of the Wetumka shale in T. 16 N., R. 15 E., where this shale is not over 80 feet thick and rests on the Winslow formation, according to D. K. Greger and Walter Berger, who have traced the Winslow formation from this point southeastward to the Muskogee quadrangle. Farther south, in T. 15 N., R. 15 E., shales and sand shales appear which belong to the Calvin and Senora formations. Still farther south and southeast, the Stuart shale, Thurman sandstone and Boggy shale appear in turn between the Calvin sandstone and the Winslow formation. The strike of the Winslow is northwest and southeast whereas the strike of the Calvin is northeast and southwest. Well logs not only indicate a gradual thickening of the known strata toward the southeast but also seem to show the sudden appearance of new strata, which are not strictly parallel to the beds higher in the section. For these reasons it seems probable that several overlaps may be present.

The major feature of the structure in the western part of the district is that of a northwestward dipping monocline with only slight variations from normal. The average dip of the strata toward the northwest is about 90 feet or one degree per mile. In places the dip is as great as 150 feet per mile and in others it is as low as 50 feet per mile. East and southeast of the outcrop of the Calvin sandstone the average dip is much less than to the west and northwest. In this district the structure of the producing sands is more nearly parallel to that of the surface beds. The variation in structure between the surface beds and the producing sands in the western part of Okmulgee county is due partly to thickening of the beds to the southeast but is also due to the fact that the deeper strata were folded slightly before the younger beds were deposited. In other words, the folding was progressing while the sediments were being deposited or at intervals during the lower Pennsylvanian. Structural data based on producing sands show that anticlines, domes, synclines and basins exist at depths where the surface indicates only minor variations in dip. Many of the pools show the presence of faulting in the beds at a depth of 100 feet or more, which is not discernible at the surface. So far, the faulting of surface rocks observed is of minor importance. Faults of 10 to 100 feet throw are known in four or five pools. These faults generally strike in a southeast-northwest direction.

In mapping structure from surface exposures one must generally rely upon sandstone beds. A careful reconnaisance before detailing is very helpful. Some sandstone beds are so cross-bedded and irregular in thickness as to be very unreliable. However, when it is possible to obtain two sandstone beds separated by a moderate interval of shale both beds can be mapped and minor irregularities may be discovered and eliminated. Local dips that cannot be verified over a distance of half a mile or more should not be depended upon, though they may be significant. Thinning of sandstone beds from 30 feet to 3 feet in a distance of a half mile is known in one instance. Hence it is important to get the thickness of the bed mapped as often as possible. Large cross-bedding features have been noted in several places. For example, in the Senora

formation in sec. 1, T. 10 N., R. 13 E., the topset and bottomset beds are 50 feet apart and show normal northwest dip whereas the foreset beds, which are thick and regular, are dipping eastward at an angle of several degrees. While sandstone beds are practically the only mappable units in this area, cross bedding is common and in many places on such a large scale as to be misleading.

The structure of the surface rocks west of Range 13 does not conform to the structure of the producing sands as well as it does east of that range. West of the range no east dip in the surface rocks is known to the writers except in connection with faulting. In Range 13 and eastward several structures show east dips at the surface. One example is in T. 12 N., R. 13 E. where a coal bed and sandstone stratum show an east dip of at least 80 feet. Also on the east side of sec. 34, T. 13 N., R. 14 E., there is approximately 30 feet of east dip. In general the surface structure of the area is that of a northwestward dipping monocline with comparatively slight undulations causing terraces, noses and small synclines. Several small faults are known in the Okmulgee district but faults are much more common in the area west of Okmulgee county in Ranges 8, 9, and 10. These faults are normal and have from 10 to 50 feet throw. The strike is northwest and southeast. The faulted structures are generally small and are regarded as indicating the presence of a trap in which oil and gas have accumulated.

PRODUCING SANDS

There are known to be six distinct producing sand horizons in the Okmulgee district and several horizons which contain stray sands. These producing sands are given below, beginning with the shallowest in the vicinity of Okmulgee:

Producing Sands in the Okmulgee District

	Depth
Cosden sand	500 feet
Salt or "Glenn" sand	1300 feet
Booch sand	1650 feet
First Dutcher sand	1900 feet
Second Dutcher sand	2000 feet
"Wilcox" sand	2750 feet

In some pools as at Youngstown, the first and second Dutcher are one sand. In the Osage Hill pool in sec. 30, T. 15 N., R. 11 E., these two sands are separated by only a few feet of shale while in the Deaner and Jameson pool in T. 11 N., R. 11 E., they are about 100 feet apart. The variation in thickness of some of the sands such as the Salt sand and Booch causes a variation in interval, which makes correlation uncertain in several localities. The interval between the Dutcher and the "Wilcox" becomes greater toward the south in Range 11 at an average rate of about 20 feet per mile from T. 16 N., to T. 12 N. Drilling to date farther south seems to substantiate this rate of increase in the interval.

The Salt sand is usually from 100 to 150 feet thick but is known in places to be more than 250 feet thick and in other places to be less than 10 feet thick. This sand is correlated with the "Glenn" sand of the Glenn pool. It is suggested that this sand outcrops as the Savannah sandstone in the Muskogee area. From 250 to 300 feet below the Salt sand is the Booch. It was discovered in sec. 21, T. 13 N., R. 14 E. on the Booch farm. Its average thickness is about 30 feet but it also varies from a few feet to as much as 300 feet in the east side of T. 13 N., R. 11 E.

Below the Booch sand in the eastern part of the county are a number of sands which have been named locally Glenn of Morris, Morris, Red Fork, Fields, Liedecker, Boynton and Wainwright sands. Outside of the pool in which these sands were named they cannot be correlated accurately with sands by the same name though they can be traced and are equivalent to sands mentioned earlier in the paper. In other words, the names applied locally are often erroneous and not consistent with earlier naming of these sands.

The First Dutcher, which the writers correlate with the First Preston sand of the old Hamilton Switch pool, lies about 200 feet below the Booch and in all probability correlates with the Morris sand of T. 13 N., R. 14 E. The Fields and "Glenn" of Morris sands together correlate with the second Dutcher and second Preston. With these correlations granted it may be stated that the first Dutcher and its equivalents varies in

thickness from 10 to 60 feet and the second Dutcher varies from about 30 to 125 feet in thickness.

The "Wilcox" or deep sand of the Okmulgee district, discovered by H. F. Wilcox in the Beggs pool, although it had previously produced oil in sections 9, 23 and 26, T. 13 N., R. 12 E., is correlated, in the opinion of the writers, with the recently discovered sand east of Bald Hill known as the Mose Carr sand and with the Detrick sand at Morris. It is also the equivalent of the Mounds sand of the Glenn pool. In the western part of the Okmulgee district this sand appears to be very thick from the logs of several wells which have drilled into it for 300 feet or more. One well reports 500 feet of "Wilcox" sand. However, it is very likely that shale or lime breaks occur which are not reported by the driller. It is apparently much thinner toward the east as no thick sands are reported at this horizon.

STRUCTURE OF PRODUCING SANDS

Owing to the variation in the intervals of the producing sands and to unconformities the structure of the producing sand in any pool is different from the structure of the rocks as revealed at the surface. A small nose or terrace at the surface is usually found to be much more pronounced at 1000 feet in depth and may be a dome or closed anticline at 2000 feet. Therefore if the possibilities of deep sands are involved it is important to make a structure map of the sand as near to the sand in question as possible.

The top of the Salt sand is seldom a reliable datum in working an area for deeper sands. There are several reasons for this. First, the Salt sand is generally thick and shaly near the top. Hence its top is not readily recognized by the driller. Second, it is often of no importance where the top is found as it carries neither oil, gas nor water. The bottom on the other hand carries water and the casing is usually set to cut it off. Therefore, the base of the Salt sand is a fairly reliable datum plane. The Booch sand can be used successfully for subsurface mapping where it is comparatively thin. When possible, subsurface structure mapping should be based on relatively thin key horizons and the nearer they are to the

supposed productive horizon the more reliable will be the result.

The regional structure of the "Wilcox" sand is that of a broad arch the axis of which extends in a northeast-southwest direction. It passes about through the pool in sec. 9, T. 13 N., R. 11 E., and a little east of Bald Hill in T. 15 N., R. 14 E., and plunges to the southwest. South of this axis the "Wilcox" sand dips south or southeast normally while to the north of this line it dips to the west or northwest. Production occurs in minor domes or anticlines on this broad arch.

The structures which produce oil and gas in the Okmulgee district are revealed at the surface almost invariably as comparatively small terraces or structural noses. In several instances these are faulted. The structures of the producing sands are more pronounced and are usually anticlines or domes though all of the sands down to and including the Dutcher produce oil and gas from open structures, i. e., terraces or noses as well as from closed structures. Observations to date have shown that in the "Wilcox" sand oil and gas do not accumulate except in closed structures with several feet of reversal. Only one exception to this rule is known to the writers and in that case there is an open structure on the Dutcher sand while not enough wells have been drilled to the "Wilcox" to determine its structure. The wells are small and it is quite probable that in this case there is a slight amount of reversal on the "Wilcox" sand.

Faulting in the producing sands also affects accumulation. In one instance at Morris, production occurs farther down the dip along the fault plane than elsewhere on the structure and is best on the upthrow side of the fault. In the South Beggs pool and also at Phillipsville there are very sudden changes in rate of dip if not actual faulting and in these cases the biggest production occurs along these very steep dips.

CORRELATION OF PRODUCING SANDS IN SOUTHEASTERN KANSAS AND NORTHEASTERN OKLAHOMA

By D. W. Williams

Contact with geologists, operators and drillers during three years of work in southeastern Kansas and northeastern Oklahoma, has impressed the writer with the general lack of knowledge concerning the relation of the producing sands of this region. It is with the hope that this condition may be somewhat improved that the present paper is offered. In the preparation of the sections which are presented, effort has been made to select very typical logs which fairly represent the conditions found in each locality.

The producing horizons chiefly discussed here are known as the Wayside and Weiser sands in Montgomery county, while in Chautauqua county, Peru is the accepted name for the main productive sand (Plate I). The correlation of these sands is an important problem from the standpoint of the operators of the district. Some believe that the Peru should be placed above the Wayside while others would put it below the Weiser sand or as low as the Labette shale. The careful classification of the limestones and shales of the Marmaton formation in this region which is here given, is believed to be essentially correct and may settle the question. This classification puts the Peru of Chautauqua county and the Wayside of the Montgomery county fields at the same horizon, in the Nowata shale. While none of the records available name the Hancock sand of Chautauqua county, it is generally understood to occur about one hundred feet below the Peru. This would undoubtedly place the Hancock sand in the Bandera shale which Plate I shows to also be the horizon of the Weiser sand of Montgomery county. The Redd sand which has produced some oil in both Chautauqua and Montgomery counties, probably should be referred to the Dudley shale although its great variation in interval from the top of the Lenapah

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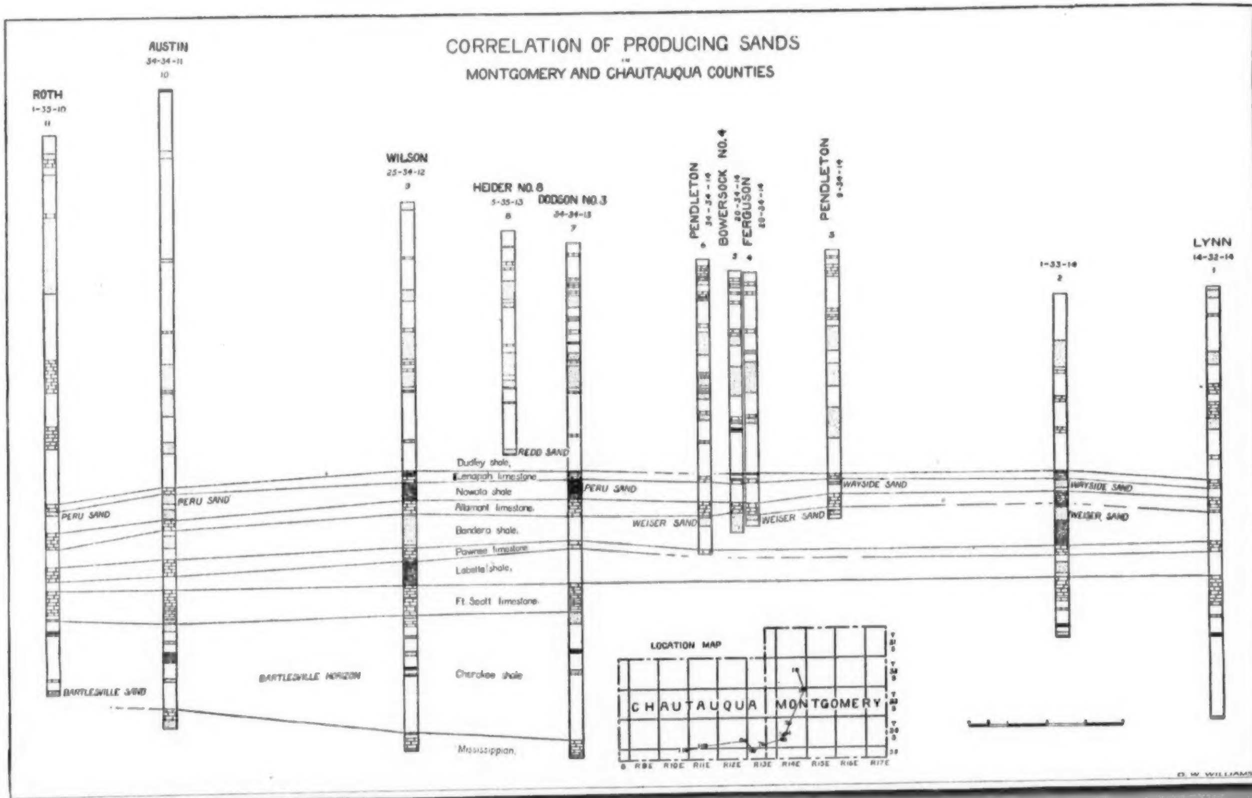


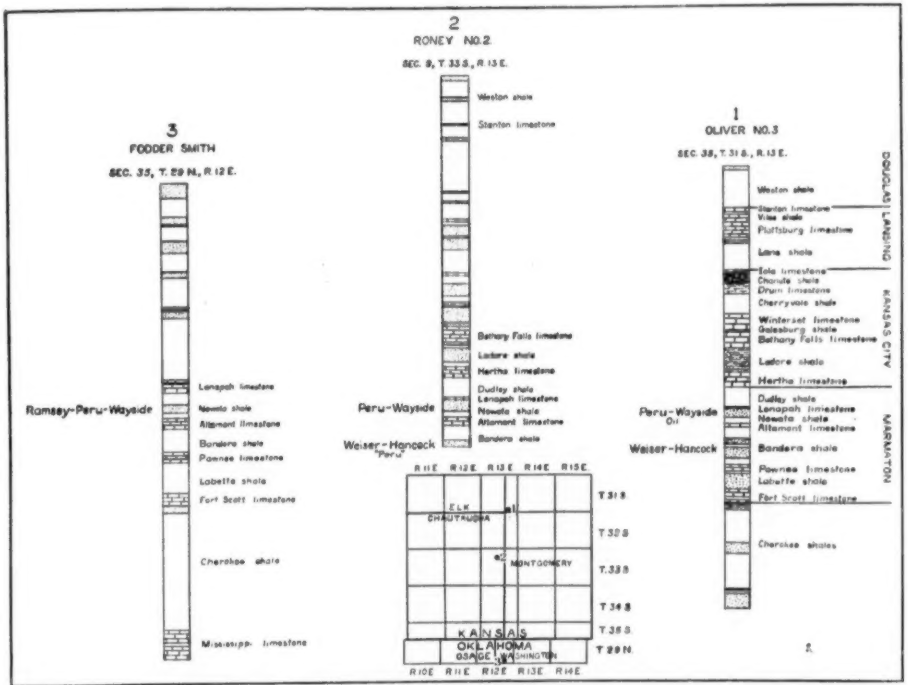
CORRELATION OF PRODUCING SANDS
IN
MONTGOMERY AND CHAUTAUQUA COUNTIES
ROTH
1-35-10
11
AUSTIN
34-34-11
10
WILSON
25-34-12
9
HEIDER NO.8
5-35-13
8
DODSON NO.3
34-34-13
7
PENDLETON
34-34-14
6
BOWERSOCK NO.4
20-34-14
3
FERGUSON
20-34-14
4
PENDLETON
9-34-14
5
1-33-14
2
LYNN
14-32-14
1
REDD SAND
PERU SAND
WEISER SAND
WAYSIDE SAND
BARTLESVILLE SAND
BARTLESVILLE HORIZON
Dudley shale.
Lenapah limestone.
Nowata shale
Altamont limestone.
Bandera shale.
Pawnee limestone.
Labette shale.
Ft. Scott limestone.
Cherokee shale
Mississippian.
LOCATION MAP
CHAUTAUQUA
MONTGOMERY
R 9E
R10E
R11E
R12E
R13E
R14E
R15E
R16E
R17E
D. W. WILLIAMS

sand is in some cases really a sand in the Ladore shale instead of the Dudley.

These sands, in common with all southern and eastern Kansas sands, are very lenticular. It was with the object of showing this condition that two logs were taken from sec. 20, T. 34 S., R. 14 E. In this case, the Wayside-Peru is entirely absent while the Weiser ranges in thickness from 15 to 60 feet in less than a quarter of a mile.

The logs shown on Plate II are chosen from a number which appear to have been recorded the most carefully and to be the most typical of each field or locality. The Oliver No. 3 (Plate II, No. 1), is typical of the formations recorded in the logs of the Elk City district. So far as is known, all the production of this area from horizons above the Cherokee shale comes from the Wayside-Peru sand in the Nowata shale. The Weiser-Hancock sand of the Bandera shale, as well as a sand in the Labette shale, is well developed but no production is reported from them. The Roney No. 2 (Plate II, No. 2), is considered to be typical of the records of wells in the Sorghum Hollow field in Ts. 32 and 33 S., Rs. 13 and 14 E., the producing areas in sec. 18 and 29, T. 33 S., R. 13 E., and of the many wild cat tests drilled in that locality. The productive horizon here is in the Bandera shale and is therefore the same as the Weiser-Hancock sand although the local name for it is Peru. The Fodder Smith (Plate II, No. 3), represents conditions found in the Ramsey field of northwestern Washington county, Oklahoma. In this case, the only well developed sand in the Marmaton formation is that producing the oil which is in the Nowata shale and is therefore equivalent to the Wayside-Peru.

The application of different names to the same sand in different localities is to be expected when development has been carried on as was the case in this field. The Peru, Wayside and Ramsey fields were developed entirely independently and for the most part by men who had no knowledge of fields other than that in which they were working. Since all the sands of the Marmaton formation are very similar in character, these men depended on the number, character and thickness of the limestones encountered in correlating the sands. Without some knowledge of geology, this method would lead



1 inch=550 feet

limestone gives color to the idea that what is called the Redd one into difficulties as may be seen by a study of Plate II. It will be noted that there is a great difference in the character of the sediments in the different wells shown, the great thickness of limestones found in the Lansing and Kansas City formations in the Oliver No. 3, having been replaced almost entirely by shale and sandstone in the nine miles intervening between this point and the Roney No. 2. While not so abrupt, the Marmaton formation shows a similar change but in the opposite direction, the limestones thinning somewhat to the north. This is especially true of the Lenapah and to a less marked degree of the Altamont and Pawnee limestones. In such cases as that shown by the log of Roney No. 2, the drillers who were familiar with territory where the Lenapah was well developed would naturally fail to recognize the thin limestone at that horizon as the Wayside-Peru cap-rock and would therefore be inclined to consider the sand found under the relatively well developed Altamont as the Wayside-Peru.

While such mistakes are very natural, they give rise nevertheless to much irritating confusion. In view of the facts as set forth in the discussion and plates, it seems inevitable that the Wayside of Montgomery county should be considered the same as the Peru of Chautauqua county and the Ramsey sand of Washington county, Oklahoma. If this conclusion is correct the Weiser of Montgomery county and the Hancock of Chautauqua county must be the same.

THE CRETACEOUS OF NORTHWESTERN LOUISIANA

BY CHESTER A. HAMMILL

Since the completion, by the Gulf Production Company, of the W. C. Agurs B-1 well, in Caddo parish, Louisiana, in January, 1920, it has been evident that previous knowledge of the Cretaceous section of northwestern Louisiana was very incomplete. Detailed study of the Bethany district emphasized this fact and led to the development of the section herewith presented. The data contained in this article were first used by the writer in July, 1920, in private reports, and are entirely the results of personal study.

From the log of the W. C. Agurs B-1 well, located in the southwest corner of sec. 6, T. 16 N., R. 16 W., a typical stratigraphic section was derived, as this log was found to correlate with the majority of other logs in this region and had the advantage of being much deeper. (See Figure 1).

Shortly after the completion of the Agurs well, the Aaron Jeter No. 1 well, about 10,000 feet southwest of it in Panola county, Texas, was deepened by the same company and came in a heavy gasser, blowing out a tremendous amount of debris from the lower part of the hole, including a great many well preserved fossils. These were readily identified as coming from the Kiamitia clays.

Several months later several sections of drill core were obtained from Jernegan No. 1 well, drilled by the Bethany Oil & Gas Company, 7600 feet south of the Jeter well. These sections of core all contain fossil *Inocerami,* characteristic of the Eagle Ford shales. The procuring of these two sets of fossils was most fortunate as knowledge obtained from the study of them was of primary importance in the interpretation of the lower portion of this section.

The following analyses of the logs of the three wells mentioned are here given, the first to show the data on which the section is based, and the other two to show the horizons from which the fossils were obtained, and their correlation with the first. (Plates I and II).

Record and Correlation of the W. C. Agurs B-1 Well, Caddo Parish, Louisiana.

	Thickness in feet	Depth in feet
TERTIARY		
Eocene		
Wilcox formation		
Clay	55	55
Pack sand	85	140
Rock	1	141
Pack sand	19	160
Midway formation		
Shale	60	220
Gumbo	30	250
Gummy shale	79	329
Rock	1	330
Gumbo	10	340
Gummy shale	125	465
Rock	2	467
CRETACEOUS		
Upper Cretaceous—Gulf series		
Arkadelphia clay		
Shale and boulders	13	480
Gumbo	25	505
Gummy shale and boulders	170	675
Gumbo	45	720
Gummy shale and boulders	80	800
Shale	20	820
Gumbo and boulders	120	940
Gumbo	4	944
Shale	11	955
Rock	15	970
Hard shale	20	990
Shale	20	1010
Gumbo	71	1081
Nacatoch sand		
Gas rock	134	1215
Marlbrook marl		
Gumbo	45	1260
Shale	40	1300
Gumbo	10	1310
Shale	52	1362
Annona chalk		
Chalk rock	133	1495
Hard chalk rock	329	1824
Brownstown marl		
Gumbo	96	1920

Upper Cretaceous—Gulf Series (continued)

Bingen formation (Eagle Ford-Woodbine)

Sand rock and sand	187	2107
Gumbo	80	2187
Hard shale	28	2215
Gumbo	5	2220
Hard shale	20	2240
Gumbo	30	2270
Hard shale	110	2380
Gummy shale	15	2395
Gumbo	5	2400

Lower Cretaceous—Comanche series

Washita group

Hard and broken lime	17	2417
Soft shale	8	2425
Hard lime rock	20	2445
Shale	12	2457
Hard and broken lime	78	2535
Sandy shale	5	2540
Hard and broken lime	178	2718
Hard sand rock	2	2720
Broken lime	75	2795
Sandy formation	5	2800
Hard and broken lime	176	2976
Hard and broken sand rock	31	3007
Hard and soft shale	60	3067

Fredericksburg group

Hard and broken lime	240	3307
Hard sand	4	3311
Sandy gumbo	11	3322
Broken lime	10	3332
Sandy shale	18	3350
Hard lime	72	3422
Sandy gumbo	6	3428
Hard lime	3	3431
Broken sand	4	3435
Hard lime	5	3440

Trinity group

Sandy lime	6	3446
Sandy shale	12	3458
Hard sand	5	3463
Broken sand	24	3487
Hard sand	3	3490
Hard lime	10	3500
Sandy shale	25	3525
Hard lime and boulders	8	3533
Hard sandy lime	31	3564

Lower Cretaceous—Comanche Series (continued)
Trinity group (continued)

Sandy gumbo	13	3577
Broken lime	6	3583
Hard and broken sand	42	3625
Hard sandy shale	18	3643
Hard and broken sand	44	3687
Sandy shale	7	3694
Hard sand	4	3698
Broken sand and boulders	30	3728
Hard sand	7	3735
Hard sandy shale	17	3752

Record and Correlation of the Aaron Jeter No. 1 Well, Panola County, Texas.

	Thickness in feet	Depth in feet
TERTIARY		
Eocene		
Wilcox formation		
Clay	20	20
Sand	5	25
Clay	20	45
Sand and gravel	147	192
Rock	3	195
Midway formation		
Gumbo	65	260
Gummy shale	225	485
CRETACEOUS		
Upper Cretaceous—Gulf series		
Arkadelphia clay		
Gummy shale and boulders	215	700
Shale and gumbo	121	821
Gumbo	72	893
Lime	7	900
Gumbo	85	985
Shale	50	1035
Nacatoch sand		
Gas rock	150	1185
Marlbrook marl		
Gumbo	130	1315
Annona chalk		
Chalk rock	470	1785
Brownstown marl		
Gumbo	58	1843
Gumbo shale and boulders	47	1890

Upper Cretaceous—Gulf Series (continued)

Bingen formation (Eagle Ford-Woodbine)		
Sand rock	52	1942
Gumbo	47	1989
Hard sand	17	2006
Gumbo	256	2262
Lime rock	4	2266
Gumbo	4	2270
Lime	8	2278
Gumbo	105	2383
Lower Cretaceous—Comanche series		
Washita group		
Broken lime	23	2406
Broken lime and sand	19	2425
Broken lime	26	2451
Hard lime	212	2663
Broken lime	37	2700
Hard shale and shell	25	2725
Red gummy shale	107	2832
Red shale	8	2840
Gumbo	15	2855
Hard shale and shells	20	2875
Broken sand	33	2908
Broken sand and shell	14	2922
Hard rock	3	2925

Record and Correlation of the Jernegan No. 1 Well, Panola County, Texas.

TERTIARY

Eocene	Thickness in feet	Depth in feet
Wilcox formation		
Sand and clay	25	25
Sand	95	120
Midway formation		
Gummy shale	40	160
Soft rock	7	167
Hard rock	3	170
Shale and sand	80	250
Gumbo	66	316
Shale	18	334
Hard gumbo	25	359
Rock	2	361
Gumbo	59	420
Rock	2	422

CRETACEOUS

Upper Cretaceous—Gulf series

Arkadelphia clay

Hard gumbo	138	560
Shale	40	600
Gumbo	28	628
Rock	1	629
Shale	14	643
Gumbo	369	1012
Shale	12	1024
Gumbo	7	1031
Shale and gumbo	46	1077

Bingen formation (Eagle Ford-Woodbine)

Hard gumbo	111	1987
Rock	17	2004
Lime	11	2015
Sandy gumbo and lime	18	2033
Gumbo	18	2051
Sand rock	4	2055
Gumbo	26	2081
Sand rock	1	2082
Gumbo	74	2156
Gypsum	4	2160
Gumbo and gypsum	82	2242
Gypsum	52	2294
Gypsum and gumbo	8	2302
Lime	16	2318
Gumbo and lime	26	2344
Gumbo and shale	36	2380

Lower Cretaceous—Comanche series

Washita group

Lime	90	2470
Sandy lime	9	2479
Lime	98	2577
Gumbo	6	2583
Hard lime	33	2616
Hard and broken sand	54	2670
Sandy shale	28	2698
Gumbo	9	2707
Sandy shale	10	2717
Gumbo	13	2730

The Tertiary is here represented by the lower part of the Wilcox formation and by the Midway formation, belonging to the lower part of the Eocene. Of these, the surface formation, the Wilcox, includes the first 120 to 195 feet. It is com-

posed of clays and sands, mostly unconsolidated, with an occasional streak of rock reported. Immediately underlying the Wilcox is the Midway formation varying in thickness from 290 to 307 feet, and consisting of gumbos, shales and streaks of rock.

The balance of the section is made up of Cretaceous (Gulf series) and Lower Cretaceous (Comanche series). Beginning at the top of the Upper Cretaceous immediately beneath

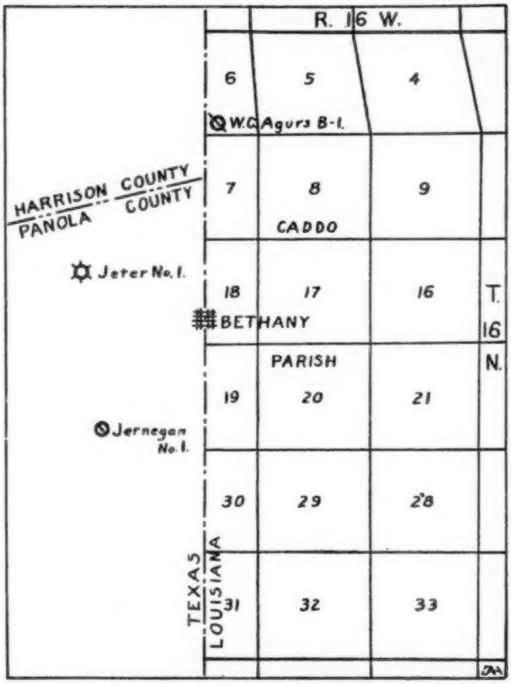


Fig. I. Sketch map showing location of wells reported.

the Midway, the first formation is the Arkadelphia clays which vary in thickness from 550 to 775 feet, and are made up of gumbos and shales sprinkled with boulders, and containing occasional streaks of rock.

The next formation, the Nacatoch sand, ranges in thickness

from 123 to 150 feet, and is a loose-grained sandy formation with occasional shale partings. The Nacatoch is commonly called the "gas rock" by drillers, and is readily recognized because of the change in drilling conditions from the overlying clays.

Below the Nacatoch is the Marlbrook marl, 130 to 157 feet thick, consisting of shales and gumbos which are in places somewhat marly. It is easily distinguished from the overlying sand and the underlying chalk.

The Annona chalk, 442 to 470 feet in thickness, is a solid chalk formation varying from hard to soft, so that parts are sometimes reported as shales or gumbos, as shown in the Jernegan log.

Beneath the Annona chalk is the Brownstown marl, a formation 76 to 105 feet thick, consisting of gumbos and shales ranging from sandy to marly in character. In carefully recorded logs the Brownstown is easily determined, but where records are carelessly kept, all or part of it is generally included with the overlying chalk or underlying Bingen formation.

Down to this point the section agrees in general with previous records. The Bingen formation as here interpreted, is the basal formation of the Upper Cretaceous, and includes the equivalents of the Eagle Ford and Woodbine. It has been widely misinterpreted in some cases, formations lying well down in the Lower Cretaceous having on several occasions been called Woodbine. The formation as here distinguished ranges from 480 to 504 feet in thickness, the upper part being predominently sandy and the middle and lower portions consisting of shales and gumbos with occasional streaks of lime and gypsum. The sandy upper portion is the horizon commonly called the Blossom sand by drillers.

The sections of drill core referred to above were taken from the member marked "gumbo and gypsum" at a depth of about 2,200 feet in the Jernegan well. These sections make up a core seven inches long and five and a half inches in diameter, and are filled with casts and impressions of *Inocerami*, characteristic of the Eagle Ford, establishing without question the age of this portion of the section.

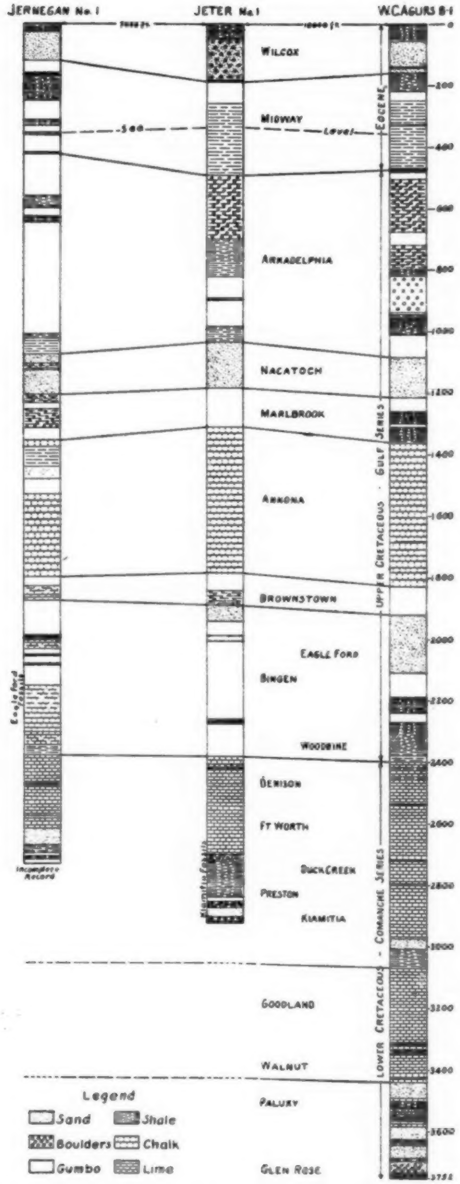


Plate I. Graphic logs of Jernegan, Jeter and Agurs wells

The line between the Upper and the Lower Cretaceous is here arbitrarily placed at th top of the prominent lime which occurs consistently beneath the series of shales and gumbos forming the lower part of the Bingen at a depth of about 2,400 feet. It is recognized that there may be difference of opinion as to the correctness of this interpretation since it has been customary to call the producing horizon generally found a few feet below the top of this lime the Woodbine. This, however, does not seem logical, since at the outcrop the Woodbine is a sand and the top of the Lower Cretaceous (the upper part of the Denison formation) is reported as a series of shales. In this district where semi-littoral conditions existed throughout the Cretaceous, it seems more consistent to correlate the shale with the Woodbine sand and the lime with the Denison shale than the lime with the Woodbine sand.

The Lower Cretaceous is made up of three groups of formations, the Washita above, the Fredericksburg in the middle, and the Trinity below. The Washita group, which has been drilled completely through only in the Agurs well, of the three under discussion, there shows a thickness of 667 feet. This group consists of the equivalents of the Denison formation, the Fort Worth lime and the Preston formation, between which it is impossible to determine lines of demarkation. Approximately the upper half of this group is made up of hard and broken limes, the remainder, of alternating shales, sands, and limes, with occasional gumbos.

The presence of the Preston formation in this group is definitely established by the Kiamitia fossils mentioned above. Since they occur above the heavy gas sand at 2,900 feet, it obviously is not the Woodbine[1].

The line between the Washita and Fredericksburg groups is drawn at the top of the very hard lime occuring consistently beneath the sand and shale series.

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[1]The fossils of Kiamitia age were obtained under the following conditions. The six-inch casing was set and cemented in the Jeter well at 2385 feet. Drilling operations then continued 540 feet below this point where a tremendous gas pressure was released which blew the tools out of the hole, wrecked the derrick, and blew out a considerable uantity of debris, including the fossils collected. Though they may have come from any point below the casing, they are very likely limited to one of the hard shale and shell horizons between 2700 and 2875 feet.

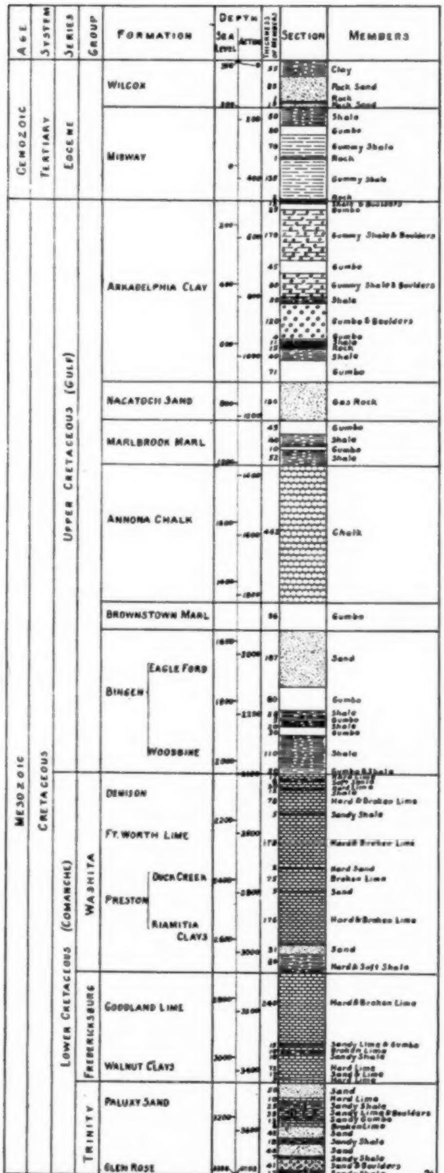

Plate II. Correlation of section in northwestern formations.

The Fredericksburg group is represented by the equivalents of the Goodland lime and the Walnut clays between which no definite line can be indicated. This group is 375 feet thick, of which the upper two thirds are hard lime and the lower one-third is mixed sands, shales, gumbos and limes, with the limes predominating.

The top of the Trinity group is drawn where the sands begin to predominate in the lower part of the section. Only 312 feet of this group have been penetrated. This probably includes the equivalents of the Paluxy sand, and at least a part of the Glen Rose formation. These formations are mainly sand and intercalated with lime, shale and gumbo.

It is unfortunate indeed that the Agurs test was not able to proceed the additional depth necessary to determine the entire thickness of the Cretaceous, and settle the question as to what underlies it in northwestern Louisiana.

Since interest in northwestern Louisiana is primarily centered in the production of oil and gas, it will not be out of place at this point to call attention briefly to the position of the various producing horizons in the Cretaceous section. The Nacatoch is the first productive formation and has come to be known as the "gas sand" because of the large amounts of gas which have been obtained from it in several of the districts. The Annona chalk is reported to have produced a few stray oil wells in the Caddo and De Soto-Red River fields, but it is in no way to be regarded as a consistent producing formation. The Blossom sand, the top member of the Bingen, has produced considerable amounts of gas in the Caddo field. One stray gas well of large capacity has been brought in in the Bethany district in this horizon. The principal oil sand of the Caddo and De Soto-Red River fields is the Woodbine. It occurs in the lower part of the Bingen above the prominent Denison lime. It is not probable that the light oil shows in the Bethany district near the top of the Denison lime are to be correlated exactly with this producing horizon. In the Bethany district the deep gas production in the south field has so far been derived from the upper part of the Preston formation. In the north field, the deep gas has only been encountered in the lower part of this formation. The deep gas sand

of the De Soto-Red River field is undoubtedly from the upper part of the Preston, correlating with the south field production of Bethany.

The question has been repeatedly raised as to the probability of production from the Trinity group. No indications are reported in the Paluxy or Glen Rose, and from the nature of the basal member, the Trinity formation, at all points known elsewhere, there is no reason to expect any favorable results from it here.

SOME STRUCTURAL AND STRATIGRAPHIC FEATURES AFFECTING RELATIVE AMOUNTS OF OIL PRODUCTION IN ILLINOIS*

By D. M. Collingwood

The main oil production of Illinois is from the southern portion of the La Salle anticline, that is, the area extending approximately from St. Francisville near the Illinois-Indiana state line in the south, in a north-westerly direction to the neighborhood of Westfield in Clark county. This paper deals with the northern part of this producing area, situated in Clark and Cumberland counties.

The chief producing horizons, since the southeastern fields were opened fifteen years ago, have been in the Pennsylvanian system, and the upper part of the Lower Mississippian series.

The curves accompanying this paper were prepared to show in a concise form the history and variations of production associated with the position of a well on the structure, the local disposition of the structure, and the thickness of the sand. It was hoped to find what, if any, definite or relative relationships applied in general to the area.

LOCALITIES REPRESENTED BY THE CURVES

The area covered includes a portion of the main anticline running slightly west of north and east of south in Clark county, through Parker, Casey, and Johnson townships. About centrally situated and to the west of this portion of the main anticline, there is a dome-like structure which is also included. This structure, with which the Siggins pool is associated, is on a parallel fold, situated in Cumberland county, Union township.

Both the main anticline and this parallel fold have west slopes steeper than the east. There is a marked syncline between the two, but the minor parallel fold does not rise as

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high structurally as the main anticline by 300 feet. The syncline plunges to the south. Its west slope flattens out south of the minor fold, until it reverses and merges into the regional southwest dip. To the north the syncline pinches out as it merges into the prevailing west dip of the main anticline.

To afford opportunity for comparison, four representative localities were selected, and a series of curves prepared to represent average conditions for a section normal to the anticlinal axis for each locality. Series 1, to the north, represents the main anticline in Parker township. Series 2, to the south, represents the main anticline in Johnson township. Series 3, in the west center, represents the isolated structure of the Siggins pool. Series 4, to the east, and slightly to the south of the Siggins pool, represents the central portion of the main anticline.

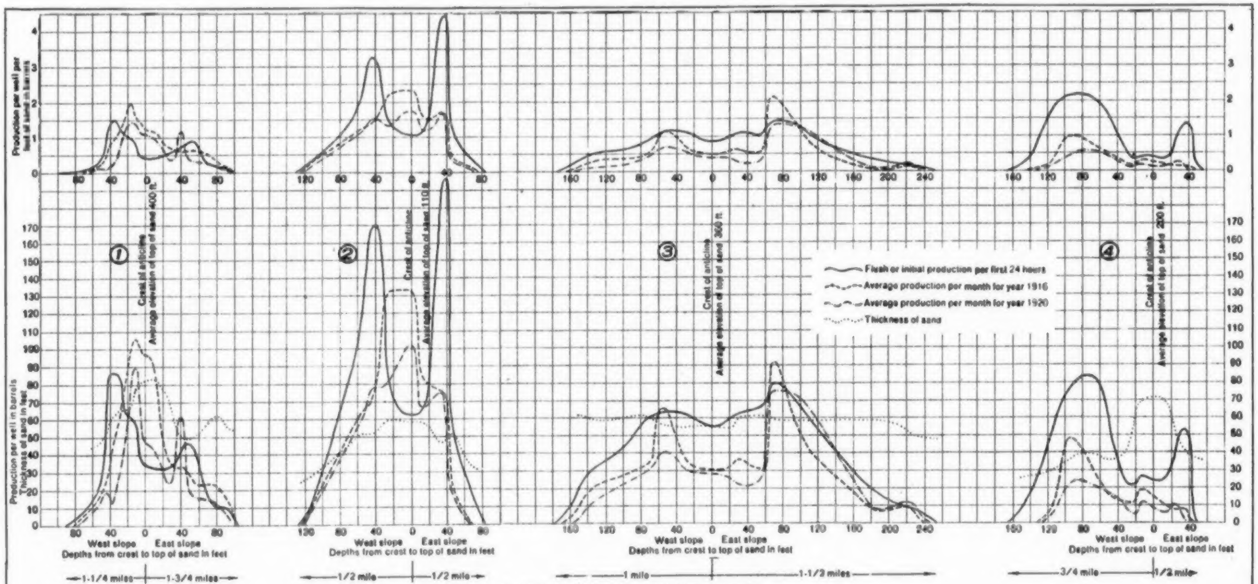
DESCRIPTION OF CURVES

The data available were collected for the main producing sand in each area. Individual well data, and average-well-of-a-tract data were arranged and averaged according to the elevation of the top of the sand. An average of the first two days' production was used to obtain initial production per 24 hours. The available data for productions of later years were the total monthly productions per tract. The average of these was used to represent the year.

The horizontal scale of the curves as plotted represent not distance but contour intervals from the crest of the structure to the top of the sand, laid off to the right for the east slope, and to the left for the west slope. According to the elevation of the top of the sand for a well or average well of a tract, productions were laid off vertically. In the lower group of each series the curves represent respectively initial production per average well per first 24 hours, and productions of later years per average well per month. In the upper group instead of gross productions the curves represent net productions per foot of sand.

LIMITATIONS IN USING DATA AVAILABLE

Although logs, records, and statistical data are rarely plen-



Production per well per feet of sand in barrels
Production per well in barrels
Thickness of sand in feet
1
Crest of anticline
Average elevation of top of sand 400 ft.
2
Crest of anticline
Average elevation of top of sand 110 ft.
3
Crest of anticline
Average elevation of top of sand 360 ft.
4
Crest of anticline
Average elevation of top of sand 200 ft.
Flush or initial production per first 24 hours
Average production per month for year 1916
Average production per month for year 1920
Thickness of sand
West slope
East slope
Depths from crest to top of sand in feet
1-1/4 miles
1-3/4 miles
1/2 mile
1/2 mile
1 mile
1-1/2 miles
3/4 mile
1/2 mile
Average horizontal distances from crest to limits of production

PLATE I

tiful, and never ideal, the data available in this case are believed to be sufficient and detailed enough to show general conditions and relationships. A few points, however, will be enumerated indicating possible minor influences on the accuracy of the averages arrived at in plotting the curves. (1) Records that would have been of value in completing a section were not available for some tracts. To avoid this difficulty localities for these sections were chosen for which most data were available. (2) In the later life of a tract total production figures sometimes include flush or initial productions due to deepening an old well in the same or to deeper sands, or to the drilling of additional wells. In this case the effect is probably a minimum because the years represented in the curves are 1916 and 1920, and most of the tracts considered had been drilled up by 1916. (3) The connection of wells to the gas pump at different times causes variations in relative production. However, as most of the tracts considered for these curves had wells first connected to the gas pump in 1917, and by 1920 most had been connected, the production averages for 1916 and 1920 will not be seriously affected.

EXPLANATION OF CURVES

To explain the curves in detail it will perhaps be best to follow through the curves in the lower group of series 3, beginning with the curve of initial production per well per 24 hours.

Starting from the zero mark of the horizontal scale it will be seen that the production from an average well on the crest of the structure from the main sand in this locality was about 55 barrels. To the left of this point the curve represents the production of average wells situated on the west slope of the structure, the horizontal scale to the left of the zero representing successive differences in elevation between that of the producing sand on the structural crest, and the elevations of the top of the sand as penetrated in the wells on the slopes. By following the curve it will be seen that the production gradually increased to a maximum of about 64 barrels at a point down the west slope where the sand was penetrated at an elevation about 45 feet below its elevation on the crest of

the structure. Farther down the slope the production falls gradually to a point about 75 feet below the crest, and then falls off more rapidly but uniformly till the position of the edge wells and limit of production in this sand is reached at a vertical distance of 180 feet below its crest. This will be called the vertical range of production.

Similarly following the curve to the right down the east

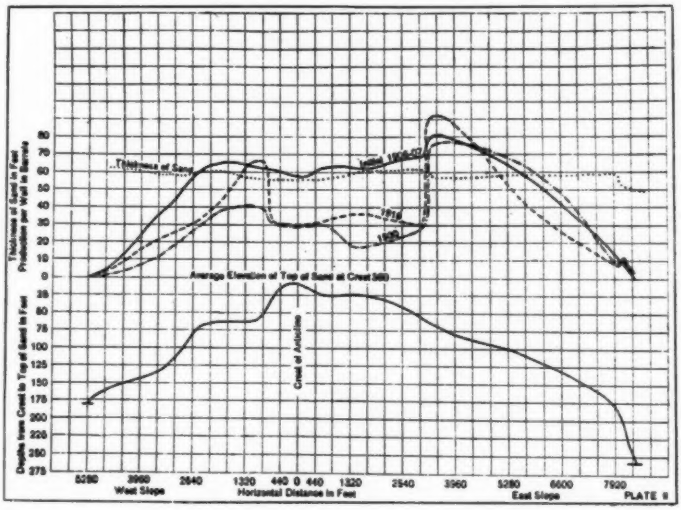


PLATE 9

slope from the zero crest line, it will be seen that the production increases, though somewhat more irregularly till the maximum production of 91 barrels is reached at a point about 70 feet vertically down the east slope. And from this point it immediately falls off at a uniformly steep rate till production ceases at the position of the edge wells on the east slope, where the sand elevation is 260 feet below its elevation on the crest. In other words the verticval range of production is 260 feet.

The curve in the lower group representing thickness of sand

INFLUENCE OF LOCAL SYNCLINE

Beside the possible influence of porosity and local irregularities of the sands, which are considered to be sufficiently local in effect to be nullified by the averages taken, there are two reasons suggested for the greater depths of maximum, and the limit of production on the inside slopes of the two parallel structures. These are, the variations in oil accumulation and pressure due to difference in degree of dip of the sand, which will be discussed later, and the funnel-like character of the synclinal trough pitching to the south and separating the two structures represented by Series 3 and 4. Tihs syncline broadens to the south with its west flank flattened, and pinches out as its trough rises to the north.

Assuming that the main oil migration was from the south and west, and in accordance with the action of gravity on oil and water in saturated strata, the oil would rise through any porous medium seeking its level of equilibrium towards the north and east. Oil traveling up through the sands in the trough of the pitching syncline mentioned above, would tend to migrate diagonally up the slopes on each side. There would be a confining action due to the syncline pinching out to the north between the two folds, and the crests of the folds on each side would stop any further lateral migration upward. Under the influence of the hydrodynamic pressure of the moving oil coming up the more gentle dip below, the oil forced up the steeper sides of the syncline, which here constitute the inside slopes of the two folds, would require the same space in the sand it had occupied farther down the slope. But owing to the steeper dip of the sands here, the oil in them would have to occupy a greater vertical distance, the greater column of oil being under increased pressure due to the confinement and restriction of the liquid under hydrodynamic pressure, as well as to gravity. This would give a greater depth of maximum, and limit of production on these inside slopes.

EFFECT OF DEGREE AND PRODUCTION OF SLOPE

From an examination of the curves in any inividual locality, it is evident that the higher initial productions and greater vertical ranges of production are associated with the steeper

slopes, other things being equal. This relationship can also be traced in some cases between the different localities represented, and seems to be true for slopes up to at least 200 feet to the mile or 2½ degrees.

From a study of a contour map of these structures along with the curves, it is found that the position of initial peak production for all localities, and also for 1916 and 1920 in Series 3 and 4, coincides either with a terrace or the first reduction or flattening of dip as the slopes approach the crest, and that the steeper the slope and the more pronounced the flattening above it, the greater is the peak production from the "flattened" area. This point, for the localities and dates cited, occurs on an average 40 feet down the slope from the crest, as noted before. In the case of the later years of 1916 and 1920 the position of peak production has moved up the slope on to the crest.

The variations of these peak production amounts in the several localities, due to the causes mentioned, are not followed in the same percentage ratio by the variations of crest productions. This indicates that the amount of peak production on the slopes is a function of the steepness of dip and amount of flattening, or in other words, the structural influence in general, while the production on the crest does not depend so directly on this influence.

With regard to the movement of the peak production positions for 1916 and 1920 in Series 1 and 2 from the slopes to the crest, it is suggested that the crest production depends more directly on thickness of sand, porosity of the sand, and amount of gas present, and that these influences become more predominant in later life, after the structural influence on the slope production has became relatively less through the removal of large quantities of oil. How they may so retard the decline of production on the crest as to cause peak production there may now be discussed in more detail.

THICKNESS AND POROSITY OF SAND

The increased thickness of the sand on the crests of the structures shown in the curves, has probably been induced in a zone of relative weakness by the same lateral pressure which

caused the major folding in this area recurring in Pennsylvanian and subsequent time. A zone of maximum strain and consequently of maximum weakness would be expected at a certain distance on each side of the actual crest. In these zones the sands would probably be rendered more porous through stress and release of pressure. Under the arch or actual top of the crest the weight of overlying strata would have nearly normal pressure. This pressure would have a compressing influence on the thickening sand as it was squeezed into the arch of the fold by the greater lateral pressure. Between these two forces the porosity of the sand might well be much reduced at the actual crest. While the lateral pressure would cause a thickening in the top of the fold, it would have the effect of thinning the sand on slopes where its normal component was of sufficiently greater magnitude.

Production peculiarities of wells on the crests will now be reviewed in an endeavor to find out whether they support the supposition that the thickened sand on the actual crest of a structure is less porous than on the slopes. In discussing the porosity of a sand at its crest with regard to oil production, the question of amount and position of any gas present will have to be considered. In this area wells producing only gas are very rare, but there is in most cases gas in close association with the oil, the main gas supply coming from the wells situated on the crest of the structure, or on slight domes along the anticlinal axis.

Three hypothetical types of crest production will be considered: (1) Production of gas only from a tight sand, (2) Production of oil and gas from a porous sand, and (3) Production of oil and gas from a tight sand.

(1) If a well produced gas only, it would be inferred that the oil remained in more porous places below the crest. The oil might not be under sufficient pressure to enter the smaller pore spaces of the crest parts of the sand, but under the differential effect of gravity the associated gas might be able to do so. A well on such a crest would not be expected to produce oil as the gas became exhausted. This condition was found in a few localities near that represented by the east slope and crest of Series 4. The structural position of this

east slope has a bearing on this fact. There is a broad flattening partially down the slope of the main anticline to the east. The Pennsylvanian measures here thin out considerably as they cap a high structure in the disconformable Mississippian lime beneath. The low oil production and its rapid decline on this slope shown in the curve would also indicate tightness or comparatively low porosity of sand.

(2) If from the strata gas and oil are produced together and the sand at the crest is as porous as it is down the flanks, there would be in all probability a flowing or comparatively large initial production. Gas liberated from solution in oil and making its way to the well is a means of carrying oil along with it and causing a large production. The gas content of a sand will certainly be greater at the crest than down the slopes with equal porosity. In this case a maximum initial production on the crest would therefore be expected. It is found from the curves however, that in no case is the initial crest production a maximum, despite the fact that the sand is often thicker there. It would seem, therefore, that the sand at the crest is, on the whole, less porous than on the slopes.

(3) The production of gas and oil from a sand at the crest having less porosity than down the slopes will now be considered. In general a high initial production due to the handicap on the gas in bringing oil through the smaller pore spaces to the well would not be expected. As has been noted this fact is borne out by the curves. The rate of decline of the oil production will depend to a large extent on the porosity. If there is a very marked difference between the high porosity on the slopes and the low porosity on the crest, a much quicker rate of decline on the crest for both gas and oil might be anticipated, particularly the latter. This is believed to be the case in the locality represented by Series 3.

On the other hand a moderate difference in porosity would be expected to cause a slower decline rate on the crest than on the slopes, but to a lesser degree. After partial exhaustion of the oil in the more porous sand on the slope, gas, always more plentiful in the higher parts of the structure, might still be aiding the movement of oil to the wells on the crest, to such an extent as to cause a slower decline rate of production there.

A time will then arrive when the crest production becomes a maximum. This is believed to be the reason for the change of peak production in later years in Series 1 and 2 from the flattened or more porous positions on the slopes, to positions nearer to or on the crests.

In general, then, the relationships shown by the curves indicate less porosity associated with thicker sand at the crests of structures.

TOTAL PRODUCTION AND DEGREE OF SLOPE

It has been observed that steepness of dip is contributary to greater vertical range of production and maximum peak amount of production. "Total productivity" of different degrees of slope may now be compared with respect to their average dip. The average dip is figured from the total horizontal distance and the vertical range of production, and does not take into consideration the changes of dip on the slopes as previously mentioned, but will serve for comparison.

Table showing total production and degree of slope in anticline in Clark and Cumberland Counties, Illinois

Series	1		2		3		4	
Slope	W.	E.	W.	E.	W.	E.	W.	E.
Productivity (initial)	550	467	420	394	510	785	392	181
Slope feet to the mile	72	57	260	160	180	166	212	200

In any one locality the west and steeper slope has the greatest productivity, with one exception. This is the east slope represented in Series 3 which was shown earlier to have been influenced in particular by the presence of the adjacent local synclinal structure. In comparing individual slopes of different localities it is found that steepness of slope is not the main controlling factor, but that the ranges in vertical and horizontal distance of production also have controlling influence. As a result of these influences, the steeper slope with perhaps a greater depth range and peak of production has about the same "total productivity" as a more gentle slope with its shallower depth range, flatter production curve, but a much greater horizontal distance of production from the crest to the edge wells. The "productivity" of later years shows the same general relationship.

CONSTRUCTION OF DECLINE CURVES

If a greater number of these production-depth curves were plotted for successive years or months, decline curves could be constructed from them, by plotting the yearly or monthly averages that correspond to the vertical depth from crest to the sand for any particular tract or well.

It is evident that the decline curves will be quite dissimilar for tracts of different sand elevations. This emphasizes how inadvisable it is to apply a general decline curve for a locality to a particular tract or well. Also that decline curves based on "weighting" according to individual initial production figures alone are liable to error unless the structural position of the tract or well is also taken into consideration.

CONCLUSION

The presentation of conditions by curves in this form should be of use in making valuations and production estimates, as an aid in constructing decline curves, and in deciding when and where to install a compressed air or other process for prolonging production in older fields.

After plotting the curves of Plate I it was found convenient to construct them for particular sections with a horizontal scale showing distance, the vertical distances between crest and elevation of sand on either slope being shown by an auxiliary curve. Plate II shows curves in this form from the same data as the lower group in Series 3. With this method, individual horizontal distance from the crest trace to each tract is represented together with average sand elevations and amount of production, but it is possible to represent the horizontal distance element only when information is complete and detailed enough to permit plotting of values for comparatively small tracts in a complete manner.

DISCUSSION

ON "SOME PALEONTOLOGICAL EVIDENCE ON THE AGE OF THE OIL BEARING HORIZON AT BURKBURNETT, TEXAS" BY L. C. GLENN.

Raymond C. Moore—Recent faunal studies of the Pennsylvanian beds of north central Texas which it has been my opportunity to make have indicated clearly the outstanding paleontological characters of most of the stratigraphic divisions which outcrop there at the surface. It has appeared that one of the most readily observed changes in fauna in the whole Texas Pennsylvanian takes place between the lower and the upper parts of the Cisco group. The lower Cisco beds, included in what has been termed the Graham formation[1], contain a prolific fauna which is very closely related to that of the Wewoka formation of southern Oklahoma. The uppermost shale member of the Graham formation is one of the most remarkably fossiliferous and distinctive horizons in the Cisco, and it has been traced from Jack county into Brown county. The succeeding beds of the Cisco are not so abundantly fossiliferous and the faunas which have been observed cannot be confused with those from horizons in the Graham. The fauna which is here reported by Doctor Girty appears to be more nearly comparable to the known fauna of the Graham formation than to another, although some of the very common and characteristic elements which are observed in collections from the outcrop do not appear to be represented in the core form the Burkburnett well.

ON "NOTES ON SUBSURFACE PRE-PENNSYLVANIAN STRATIGRAPHY OF THE NORTH MID-CONTINENT FIELDS" BY F. L. AURIN, E. A. TRAGER AND G. C. CLARK.

M. J. Millard—Mr. Aurin intimates that the Tucker sand in the Drumright pool is the "Wilcox" sand. It is probably a bit dangerous to carry correlation on a lithologic basis for the reason that it may fail when carried over long distances. While the Tucker and "Wilcox" sands are green in color, they are very likely two different sands. Two facts will substantiate this statement. (1) In the NW corner of the NE ¼, sec. 16-16-8, a well was drilled by Frank Gillespie to a depth of over 3500 feet. A partial log is as follows:

Bartlesville sand	2640-2665
Tucker sand	2745-
Pay sand	3531-3563

The last sand was preceded by a body of green shale such as is found above the "Wilcox" sand. (2) If the contours on the "Wilcox" sand over the area between the "Wilcox" wells in Okmulgee county and the Bristow area are projected, it will be found that the above deep sand coincides with the "Wilcox." In my opinion the "Wilcox" sand, if pro-

[1]Plummer, F. B., and Moore, R. C., Stratigraphy of the Pennsylvanian of north central Texas.

ductive, exists at a depth approximately 900 feet below the Bartlesville sand in the Drumright pool. It is rumored that one company has penetrated this deep sand and has obtained production.

C. A. Hammill—I feel that highest commendation and appreciation are due those who have made possible the presentation of the splendid papers we have just heard. It is generous contributions of just this type that are rendering noble service in creating closer relations between the commercial and the scientific sides of the petroleum industry.

One matter cannot be allowed to pass without an expression of regret. It is indeed unfortunate that such wide and accepted currency is being given to the term "Wilcox" sand in Oklahoma at this time. This term directly conflicts with the Wilcox formation (lignitic sands and clays) of lower Eocene age which extends across the states of Texas, Louisiana, and Arkansas, and which has been known by that name for several years. In justice to and in accordance with the accepted practice of avoiding duplication of formation names, I earnestly suggest that the members of this association lend all efforts possible to adjust the error or at least see that in their references to the "Wilcox" sand of Oklahoma the name is properly quoted.

Dr. I. C. White—In connection with this splendid paper of Mr. Aurin, I desire to utter a word of commendation for the broad and liberal policy of his employer, Mr. E. W. Marland, President of the Marland Company. His example in not only permitting but encouraging the members of his geologic staff, of which Mr. Aurin is one, to prepare for publication on the data secured from the operation of his company's drills, and those of others over such an extensive area, cannot be too highly praised. Mr. Marland has followed the teachings of geology in all of his oil and gas operations and this accounts for his wonderful success in the oil game.

W. C. Kite—Mr. Aurin's section from the Ponca field north through the Butler county fields shows a marked convergence of the formations that lie immediately above the Mississippian rocks. This thinning and pinching out of the sands would tend to alter the subsurface structure of folds in that territory. At the Dallas meeting last year Mr. Aurin stated that there is a very marked convergence of the formation westward from the Ponca field toward the Blackwell field. Now with the recent activity to the west of Blackwell, I am very curious to know if Mr. Aurin finds this north and west convergence continuing west of the Blackwell field.

ON "THE WEST COLUMBIA SALT DOME, BRAZORIA COUNTY, TEXAS," BY D. C. BARTON.

J. B. Overstreet—A point in connection with the flank sands at West Columbia is that well logs have shown that the producing sands are in general underlain by a black shale. A belt of this shale which is nonproductive lies between the producing area and that underlain by the

salt core. This condition is also found at Humble, and possibly indicates that this body of shale was thrust up with the salt core, and is thought by many to be the original source of the oil. Fossils from a well on the southeast side of the dome at a depth of 2800 feet were identified as Upper Cretaceous forms *(Inoceramus)*. Mr. Barton has said that no oil has been found in the cap rock. One and possibly two wells on the southwest side of the dome produced a small amount of heavy oil from the cap rock at about 480 feet.

Dr. I. C. White—In the accurate temperature measurements of Mr. Van Orstrand, physical geologist of the U. S. Geological Survey, several wells have been tested in which the temperature fell with increased depth for a hundred feet or more. In all such cases the irregularity was due to the presence at the depth in question of a flow of natural gas. In the I. H. Lake well, Marion county W. Va., the deepest (7579 ft.) boring of the world, a case of this kind occurred below a depth of 6800 feet while the drill was passing through the bituminous shales of the Hamilton beds. I think the temperature data given by Mr. Barton are readily explainable through the expansion of the large quantity of natural gas present with the oil in the immense wells of the West Columbia dome.

Wallace E. Pratt—Mr. Barton has stated the age of the rocks penetrated at West Columbia as Miocene (possibly uppermost Oligocene) and younger. In this statement he is, I think, correct, but the discussion has brought forth the statement that Cretaceous fossils have been encountered in wells at West Columbia. This is also true, I think, and the depths at which Cretaceous fossils are found are not excessive, either. How can this apparently contradictory state of affairs be explained?

Wells drilled by the Humble Company at West Columbia have encountered Foraminifera which are identified beyond question as Cretaceous types. Wells drilled by other companies, as stated by Mr. Overstreet, have encountered larger forms which indisputably represent Miocene age. The same Cretaceous fossils can be found elsewhere in Miocene beds in the Gulf Coast region not only in wells but on the outcrop. Rolled Cretaceous fossils including Foraminifera are common in the sands and clays of the Fleming along its outcrop in Grimes county. Thus the Cretaceous fossils in Miocene rocks at West Columbia are without doubt derived from a former land mass of Cretaceous rocks which was eroded in Miocene time, the fossils being transported to the Fleming seas and there redeposited.

ON "RELATION OF THE BASE OF THE RED BEDS TO THE OIL POOLS IN A PORTION OF SOUTHERN OKLAHOMA," BY G. E. BURTON.

W. J. Millard—In declaring that the thinness of the Red Beds near the Healdton and Hewitt pools was due to deposition around a folded region and not to erosion, Mr. Burton intimates that the folding oc-

curred previous to Permian time. There may have been some folding previous to the deposition of the Red Beds but there was folding after the Red Beds had been deposited. In working out the Hewitt pool for the Texas Company in 1916, distinct evidence of a fold was found in the Red Beds. That movement along a line of weakness may be prolonged over a considerable period of time is evidenced in the fold south of Madill, Oklahoma, which is distinctly traceable parallel to the Arbuckle Uplidt, in Cretaceous sediments. There is hardly much doubt that this fold is related to the folding found in the general vicinity of the Arbuckles.

C. A. Warner—I would like to ask Mr. Burton whether the relation of thin Red Beds to producing fields is true of all southern Oklahoma, or applies only to the region in the vicinity of the Arbuckle Mountains and if this applies to all southern Oklahoma, how the apparent great thickness of Red Beds at Cement is accounted for.

ON "GEOLOGY OF THE CAT CREEK OIL FIELD, FERGUS AND GARFIELD COUNTIES, MONTANA," BY C. T. LUPTON AND WALLACE LEE.

Frederic H. Lahee—The oil at Cat Creek I understand, is backed by fresh water, water so fresh that one can drink it. This seems to me to be a very important point which might well receive consideration in any attempt to explain the source and manner of accumulation of the Cat Creek oil.

I agree with Mr. Lee that the high gravity of this oil (in the Kootenai) is probably, at least in part, due to filtration, and that the accumulation was probably dependent on migration from some source along the faults which intersect the structure. Bearing on these ideas, I would like to call attention to two facts, (1), that the Colorado shales above the Kootenai yield similar high grade oil at numerous horizons, sometimes so abundantly as to make drilling down to the Kootenai sand very difficult, and (2), that the Quadrant formation, thought to be equivalent to the Embar in Wyoming, yields heavy oil. These facts should be taken into account in connection with the suggestion made by Dr. David White, that the high gravity of the oil in the Kootenai and the high fixed carbon ratios of the Cretaceous coals in this region may be parallel metamorphic effects of the relatively intense deformation to which the containing strata have been subjected. In other words, is it not well to emphasize that both of these factors, namely, regional metamorphism and what may be called local filtration, may have cooperated in producing this high gravity oil?

Mowry Bates—The high gasoline content is probably due to the intense folding as in the Garber field in Oklahoma. The oil contains 55 percent of 53 gravity first run gasoline. The reversal in this structure is 220 feet on the surface and much greater with depth. It is the greatest reversal of any producing field in Oklahoma.

it is a well established fact that carbonization of coal takes place in local metamorphism in considering the character of petroleum deposits, since it is a well established fact that carbonlization of coal takes place in local areas where heat and pressure have been more intense. The anthracite coal at Cerillos, New Mexico is a case in point since it occurs in a district where regionally the coal is of a sub-bituminous, low-carbon character, but local metamorphism produced anthracite. I believe the remark of Mr. Bates is well taken, that the intensity of the folding in the Garber, Oklahoma, field may have something to do with the high gasoline content of the petroleum.

Edward Bloesch—I wish to ask how we may explain the heavy oil in the Quadrant formation in the same territory. This formation has certainly experienced the same metamorphic action as the younger strata.

ON "GRAPHIC METHOD OF DETERMINING LOCATION OF AXIS OF ASYMMETRICAL FOLDS AT VARIOUS DEPTHS," BY D. M. COLLINGWOOD.

K C. Heald— I note that Mr. Collingwood assumes, as do several other authors, that the folding is parallel. I would like an expression from geologists who are acquainted with conditions in simply folded regions, regarding the justification for this assumption.

C. W. Tomlinson—I am informed by Mr. C. J. Hares that in the Grass Creek field, Wyoming, the crest line of the anticline in the chief producing sand, roughly 1000 feet deep, is offset toward the steeper flank of the fold, as compared with the crest line at the surface. In this case the folding evidently is not strictly of the parallel type. The chief body of shale has suffered thinning on the steeper flank of the fold, between more resistant members. Such conditions are more apt to be encountered in a region of strong folding than in one where gentle folding and low dips predominate.

Frederic H. Lahee—Mr. Collingwood's paper interests me since I was led to make a rather extensive study of this subject about a year ago when there seemed to be reason for believing that a certain well, which was being drilled on an asymmetrical anticline, was incorrectly located. I will not enter into details here, but will merely call attention to the fact that, as shown in Figs. 1 and 2, there are considerable differences in asymmetrical anticlines, between those which are of the similar pattern and those which are of the parallel pattern.

In locating a well for oil we are interested, not in the geometric crest of the fold, but in the highest part of the fold. Thus, in Figs. 1 and 2, *a* is the geometric crest of the anticline at the surface of the ground, whereas *c* is the highest point exposed in the anticline. When I refer to "highest point," I mean in reference to the structure, and not to the stratigraphy. Any accumulation of oil, under ideal conditions, would be

primarily related to *cd*. Furthermore, on the surface of the ground, the geologist would be more likely to find the change of dip *c*, than the position of the axial plane, *a*. Observe that in an ideal anticline of the similar type (Fig. 1) *cd*. or the "crest line," is parallel to the "axial line," *ab*, but it is on the side of *ab* toward the low-dipping limb; and

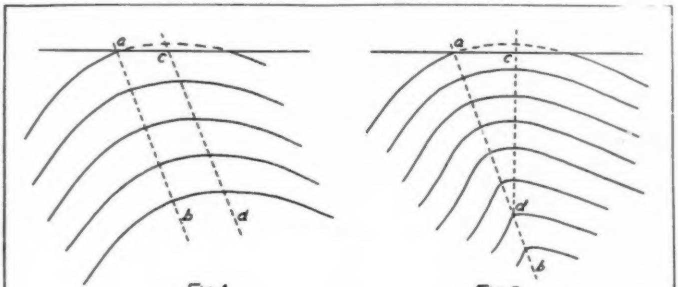


Fig. 1 Fig. 2

that in an ideal anticline of the parallel type, *cd* is vertical down to the point where the curvature of the fold becomes acute, and there it *(cd)* becomes coincident with the axial line, *ab*. Of course, in nature, these ideal forms do not exist, but folds may approximate one or the other of the two types. It is well, therefore, to bear in mind these theoretical relations, particularly in regions of rather pronounced folding.

ON "GRANITE IN WELLS IN EASTERN NEW MEXICO," BY W. T. LEE.

John Rich—On the east side of the Estancia Valley, New Mexico, is a long strip of pre-Cambrian rocks surmounted by monadnocks of which Pedernal Peak is one of the most prominent. There is a conspicuous absence of debris derived from this pre-Cambrian area in the Red Beds surrounding it and overlapping unconformably upon it. It required a careful search of many exposures of the Red Beds near the contact to reveal any fragments of the pre-Cambrian rocks, and it was only in the lower 10 to 20 feet above the contact that they could be found.

Wallace E. Pratt—As I understand Mr. Lee suspects that wells reported to have encountered granite in eastern New Mexico and western Texas have, in fact, simply encountered granite boulders and conglomerate at the base of the Permian Red Beds.

Referring to wells in the Panhandle of western Texas, it appears unquestionable that true granite has been encountered. In the gas field north of Amarillo these wells go through the Red Beds at about 1300 feet, passing into rock salt which overlies blue shales and, beneath that, gray

dolomitic limestone. From the dolomitic limestone which contains gas and shows of oil, the wells go directly into granite which is weathered and disintegrated where first encountered but within a few feet becomes fresh and hard. In some wells little or no disintegrated material or detritus is encountered but fresh granite lies immediately below dolomite. The dolomite is not metamorphosed and the granite is apparently older than the overlying sedimentaries. We have at Amarillo, therefore, something very like the buried granite ridge in Kansas, and not the situation which Mr. Lee suspects.

R. C. Moore—The Granite ridge of Kansas, or as it has been called, the Nemaha mountain range, for there is little question but that during a part of the late Paleozoic time this was an elevated mountain mass similar to the Arbuckles and Wichitas of southern Oklahoma, was very evidently uplifted before the post-Pennsylvanian orogenic movement which formed the Ancestral Rocky mountains of Doctor Lee. Detailed studies of numerous well records in central Kansas which are now available, and resulting knowledge of the subsurface geology of the region which has in part been presented at this meeting and in previous publications[1], show convincingly that Ordovician to Mississippian strata which are upturned on the flanks, and in part extended over the Nemaha granite were deeply weathered and eroded prior to the burial of the range by Pennsylvanian sediments. In different places the drill appears to pass from the overlapping Pennsylvanian into Mississippian, Ordovician, or directly into granite. In the southern part of the ridge beds of Cherokee and basal Marmaton age are in contact with the pre-Pennsylvanian rocks, but in the north the lower part of the Wabaunsee, the uppermost of the Kansas Pennsylvanian formations, is in contact with the granite.

It may be of interest in connection with Doctor Lee's discussion of the Pennsylvanian-Permian boundary in New Mexico and the reported discovery of lower Cisco fossils in the Abo sandstone by Bose, to call attention to the fact that the only large stratigraphic break in the Pennsylvanian-Perman of the Mid-Continent region farther east is correlated with the uplift of the southern Oklahoma mountains. North of the Arbuckles and apparently also to the south, it is hardly possible to distinguish the so-called upper Pennsylvanian which is in part red, from the succeeding basal Permian although these strata rest with distinct, and locally pronounced unconformity on the earlier Pennsylvanian. In northern Texas, there is much evidence that this orgenic movement and its accompanying stratigraphic break, occurred in lower Cisco time. May this break correspond to that at the base of the Manzano group? If so, the Ancestral Rockies correspond in age to the Arbuckle-Wichitas of southern Oklahoma. If there was a considerable

[1]Moore, R. C., The relation of the buried granite in Kansas to oil production, Bull., Am. Assn. Petrol. Geol., vol. IV, pp. 255-261, 1920.

and widespread diastrophic movement at this time does it actually belong in the Pennsylvanian or may it mark the line of division between two periods?

J. W. Beede—The fossils on which Bose and Baker made their correlation came largely from Tularosa, about 12 or 15 miles north of Alamagorda. A small amount of material from that locality was in my hands prior to the publication of the paper on the Diablo plateau.

It was not critical material but had a Pennsylvanian aspect. It was from beds of different lithological character from the beds of the Hueco Escarpment which I had studied, and for that reason it was more or less tentatively referred to the Pennsylvanian. There may be an overlap of sediments to the south so that somewhat older sediments appear at Tularosa than occur in the Huecos. I suspect that Dr. White and Dr. Girty are correct in referring much of the Abo to the basal Permian.

Arthur Eaton—About two years ago a well was completed by the Continental Oil Company on the Baker Ranch, which is situated on Cimarron river in northeastern New Mexico. The Dakota sandstone is exposed along the rim of the canyon forming a steep escarpment and the well is located in the bottom of the canyon starting approximately at the top of the red beds. At about 2500 feet a very hard rock was encountered and after drilling in this for some two hundred feet it was decided to back up in the hold and drill a shoulder, afterwards knocking off the shoulder and obtaining with a bailer samples of the formation. This was done and a sample was obtained from a depth of 2590 feet. These samples, some of them two inches in diameter were coarse pink granite showing no weathering. The drillings below this depth were all of the same character. Under the microscope it was seen that nothing but granite had been encountered below the point where the shoulder had been drilled. The results of this well showed unquestionably that in this locality at least the red beds were almost immediately underlain by a granite mass.

EDITORIAL

The annual influx of new geologists, the products of the colleges and universities of the country, is now at hand. These students of geology, either undergraduates desiring a position for the summer or graduates desiring permanent employment, enter the commercial field this year at a time when the price of oil has been greatly reduced and when new positions are very scarce. Of the great number of applicants almost all and even many of the good men wander from office to office in vain looking for employment. It is believed that few of these men look upon oil geology as a branch of the oil industry and that few of their educators so consider our work in their courses of education.

Oil geology is the application of the science of geology to the oil business. It is therefore on the dividing line between pure science and business and many of our number make their specialty either the scientific or business end through choice or necessity. We owe our livelihood as oil geologists to an industry, to a business. No matter what our present occupation may be we consider ourselves trained as scientists and therefore able to think more clearly and more efficiently along general lines than men who have not had the advantages which have been our lot.

As we look about us in this business atmosphere we find that a notable percentage of those by whom we are employed have had no such advantages as we have had. And yet few of our number have attained positions such that they can employ geologists. Is it not therefore obvious that we, as oil geologists, should acquaint ourselves with the oil business more than we are now doing and should urge the students of geology who are asking for a place in our midst to learn the practical end of the business so that they will be able to make their mark either as superintendents acquainted with geology or as geologists when they have broadened their viewpoint by contact with our business conditions?

S. P.

GEOLOGICAL NOTES

OIL DEVELOPMENTS IN THE TEXAS AND LOUISIANA COASTAL FIELDS DURING 1920

During 1920 the Texas and Louisiana Gulf Coast fields produced approximately 32,000,000 barrels of oil. No new fields were discovered but certain of the older fields were intensively developed in such a manner that an increase in production of about 8,000,000 barrels was realized. Such fields as Barbers Hill, Batson, Goose Creek, Sour Lake, Spindletop, Jennings and Vinton showed decreases in production amounting to about 1,200,000 barrels. However, the production at Blue Ridge, Damon Mound, Hull, Humble, Markham, Saratoga, Somerset, West Columbia and Edgerley showed an increase of some 9,200,000 barrels.

The total number of completions in the coastal fields during 1920 was 745, compared with 631 in 1919. It is interesting to note at the same time that 600 of the 1920 completions were producers while only 389 of the 1919 completions were classed as producers. The total initial production realized from the 1920 completions was 448,000 barrels as compared with 249,000 barrels initial production in 1919.

REVIEW BY FIELDS

West Columbia Field.—During 1920 a new producing area was developed on the north side of this remarkable coastal dome. The No. 1 Abrams well of the Texas Company which started the development on the north side came in with an initial production of about 26,000 barrels per day, and at the close of the year it had probably produced in the neighborhood of 2,500 barrels of oil. No other wells were brought in in this area with as large initial production but there were quite a number which made 10,000 barrels per day or more. Only 95 wells were drilled in this field during 1920 and of this number 72 were producers with a total production of 241,150 barrels. During the year this field produced 10,500,000 barrels of oil from an area of approximately 160 acres. At the close of the year a daily production of around 40,000 barrels per day was maintained and an attempt was being made to extend the 3000-foot producing sand to the northwest of the dome. Also an attempt was being made to connect up the deep producing sand in the vicinity of the Abrams with the producing area to the east of the field. There is probability that during 1921 considerable new production will be brought in on the northwest and northeast sides of this dome.

Hull Field.—The Hull Field in Liberty county was exceedingly active during 1920 with 148 completions of which 119 were producing wells with a total initial production of about 96,000 barrels. During 1919 there were only 66 completions in this field of which 39 were producing wells. At the close of the year the daily production was still on the increase and it is quite probable that this field has not yet reached its

maximum. At the close of the year the daily production was close to 30,000 barrels. The production in this field comes from a deep sand which encircles the salt dome to the east, southeast, south and southwest.

Goose Creek Field.—Production in this pool declined 1,000,000 barrels during 1919 despite the fact that there were 114 completions . However, in 1920 the production decreased 3,000,000 barrels with 117 completions. At the close of the year a daily production of about 15,000 barrels was being maintained. Considerable exploration work took place in this field in an attempt to develop a deeper producing sand. Several wells were drilled to depth of over 4200 feet and very encouraging results were obtained. While it is generally believed that a salt dome underlies this field no actual dome formation has yet been found. This gives rise to the opinion that production at Goose Creek will be obtained at greater depth than in any of the other producing fields on the Gulf Coast, and makes Goose Creek's future very encouraging. It is generally believed that during 1921 wells of large capacity will be brought in at a depth of between 4200 and 4500 feet. If such is the case the future of the Goose Creek field will rest almost entirely with the technical problem of developing rotary drilled wells as great depth.

Damon Mound Field.—During 1920 this field produced about 1,300,000 barrels of oil as compared with 300,000 barrels in 1919, a net increase of about 1,000,000 brarels. During 1920 there were completed in this field only 27 wells of which 18 (or 66 2-3 per cent) were producers. From these 18 producing wells a total initial production of 18,735 barrels was obtained. This is the highest initial production per producing well brought in of any of the coastal fields with the exception of West Columbia and speaks well for the geological supervision maintained over drilling operations by the Sinclair-Gulf Company, the principal operator. The producing area of this field is extremely limited, due to the high dip of the producing sands away from the dome.

Tests Outside Proven Fields During 1920. During the year there was a considerable amount of drilling outside of the proven fields and such salt domes as Stratton Ridge, Davis Hill and Hockley were given a considerable amount of testing. All of these domes as well as the South Dayton dome in Liberty county have great potentialities as future producing fields, and it is quite possible that during 1921 one or more of them will be brought into the producing class. However, at the beginning of the year 1921, it looks as if "wild-catting" operations were going to be exceedingly restricted with the price of coastal crude going down and the exceedingly stringent financial situation. The only feature which is at all encouraging to companies carrying on "wild-cat" operations is the fact that the price of material and labor will probably decrease during the year, which will make it possible to carry on these operations much more cheaply.

FUTURE OF THE COASTAL FIELDS

In discussing the probable future of the producing fields of the Texas and Louisiana gulf coastal plain, it must be borne in mind that the matter of posted price per barrel is the most vital consideration in so far as the operators are concerned. Leases in the salt dome fields, where the wells have an exceedingly high flush production during the early stages of development, are a very valuable asset even with oil selling as low as 50 cents per barrel. However, with the exception of West Columbia and Hull, all of the coastal fields have reached the stage where it is in many cases unprofitable to operate at less than $1.50 per barrel for oil. As the fields get older and the daily production of the wells becomes less, the cost per barrel of producing oil will mount very rapidly unless the technology of efficient operation is developed to a much higher stage than at present.

The price of coastal crude has always been governed in the past by its value as a fuel oil although all of the coastal crude oils have very high lubricating values. It is probable that this same condition will prevail during 1921 and the following points in this connection are of great interest to coastal producers. During 1920 in addition to the 32,000,000 barrels of oil produced by the coastal fields, there were imported from Mexico through the ports from New Orleans to Port Aransas about 43,000,000 barrels of fuel oil. This approximates one quarter of the total production of the Mexican fields during 1920.

Some observers of the Mexican situation are inclined to believe that the production of the Mexican fields will decline very perceptibly during 1921 which will make it exceedingly difficult to maintain this amount of imports. Others hold that Mexican production will be maintained during 1921.

Therefore, if the present financial stringency is somewhat relieved during 1921, as everyone expects it to do, there is reason to believe that the price of coastal crude may reach $3.00 per barrel. Under these conditions it is quite probable that 1921 will be a very active year and it is reasonable to believe that new producing areas will be developed.

The Production of Petroleum in Texas and Louisiana Coastal Fields in Barrels During 1919 *and* 1920

Texas Gulf Coast:

Field	1920	1919	Increase	Decrease
Barbers Hill	136,367	169,415	———	33,048
Batson	484,036	511,400	———	27,364
Blue Ridge	173,087	24,910*a*	148,177	———
Damon Mound	1,259,375	289,550	969,825	———
Goose Creek	5,666,384	6,375,935	———	709,551
Hull	4,468,612	1,183,480	3,285,132	———
Humble	3,692,108	3,193,960	498,148	———
Markham	75,774	71,485	4,289	———

Saratoga	791,920	634,922	297,618	———
Sour Lake	2,073,483	2,509,517	———	436,034
Somerset	245,140	94,100	151,040	———
Spindle Top	323,995	446,485	———	122,490
West Columbia	10,563,748	6,771,605	3,792,143	———
Total	29,954,029	22,307,764	9,146,372	1,328,487

Net increase in production for 1920..............................7,817,885 Bbls.

Louisiana Coastal Fields

Field	1920	1919	Increase	Decrease
Edgerly	480,218	358,245	121,973	———
Jennings	244,328	333,785	———	89,457
Vinton	1,312,087	1,462,335	———	150,248
Total	2,036,633	2,154,365	121,973	239,705

Net decrease in production for 1920..............................117,732 Bbls.

COMPARATIVE DRILLING RECORD

Comparative Drilling Record Texas Fields 1919 *and* 1920

District	Completions 1919	Completions 1920	Producers 1919	Producers 1920	Failures 1919	Failures 1920	Initial Prod. 1919	Initial Prod. 1920
Gulf Coast:								
Barbers Hill	22	16	14	5	8	11	3520	807
Batson	8	41	7	39	3	2	102	4967
Blue Ridge	2	15	1	9	1	6	600	8530
Damon	19	27	7	18	7	18	700	18735
Dayton	2	....	1	....	1	....	400	....
Goose Creek	117	114	66	93	51	21	29432	41476
Hull	66	148	39	119	27	29	50355	95939
Humble	121	74	71	57	50	17	5990	22039
Markham	12	7	10	4	2	3	361	1060
Saratoga	39	70	22	65	17	5	1203	4713
Sour Lake	53	27	39	29	14	8	3428	3199
Somerset	38	72	34	72	4	0	527	853
Spindletop	24	29	19	18	5	11	1022	4375
W. Columbia	108	95	61	72	47	23	150975	241150
Total	631	745	389	600	242	145	248615	447843

a. Nine months only.

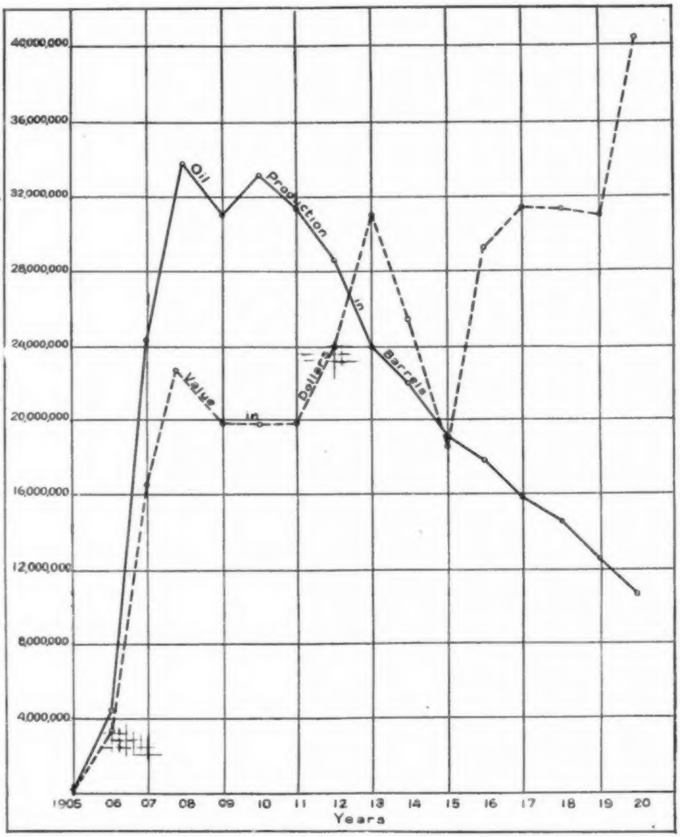
JOHN SUMAN.

DEVELOPMENT IN ILLINOIS OIL FIELDS DURING THE YEAR 1920

The Press Bulletins issued by the State Geological Survey and reviewed for this Association indicate some of the more conspicuous phases of recent geological studies in Illinois. Considerable private

work has been done in addition to investigations financed by the state, and our knowledge of underground conditions is being augmented and revised.

According to L. A. Mylius, who is in charge of oil investigations for



the State Geological Survey, there are nearly 19,000 producing oil wells in the state, with a daily production close to 30,000 barrels. The larger part of this amount comes from the eastern Illinois field, which comprises portions of Lawrence, Crawford, Jasper, Clark, Cumberland, and Coles counties. The remainder of this production is scattered over some 8 counties in southern and western Illinois.

The accompanying diagram (Fig. 1) shows the total production of Illinois in 1920, and its value. The curve of value of production shows an increase which is the more notable because of the decline in total production.

In view of the fact that glacial drift covers the surface in all of the Illinois fields, the following table, which records total number of well drilled, and those which were dry, may be of interest:

Table of Wells Drilled and Dry Holes in Illinois, 1906 to 1920 Inclusive

Year	Total Completions	Dry Holes	Percentage of Dry Holes
1906	3,283	490	14.9
1907	4,988	728	14.6
1908	3,574	555	15.5
1909	3,151	558	17.7
1910	2,149	393	18.3
1911	1,365	263	19.3
1912	1,260	257	20.4
1913	1,721	278	16.2
1914	1,579	356	22.6
1915	756	197	26.1
1916	1,469	317	21.6
1917	674	172	25.5
1918	410	120	29.3
1919	368	104	28.2
1920	314	100	31.8

Total wells drilled to January 1, 1921....27,069
Total dry holes drilled to January 1, 1921....5,129
Percentage dry holes drilled to January 1, 1921....18.97

The percentage of dry holes compares very favorably with the record in other states, such as Oklahoma, Texas, California, etc., where the geologist is not handicapped with such a paucity of bed rock outcrops as he is in Illinois. The increase of bed rocks in the annual percentage of dry holes indicates, however, that exploratory work should be conducted according to the most approved methods, and that all possible use should be made of geology and similar studies which help to minimize the element of chance.

Much of the more recent wildcat drilling has been done with the hope of extending the productive Trenton area in Illinois. Upper zones, however, remain untested over large areas. In the northern part of the state there are two or three horizons which merit careful testing because they are known to be productive elsewhere in Illinois and Indiana. The productive horizons increase in number as one goes southward to some ten or twelve prospective oil sands in the southern area. Of the 102 counties in Illinois, perhaps all but a dozen or so are worthy of careful study with reference to oil and gas production.

The past season has demonstrated the value of the diamond drill for

testing new ground to depths up to 900 or 1,000 feet. A correct interpretation of the cores so obtained makes it possible to determine more or less accurately the structure of the underlying rocks. In addition the water or oil content of these rocks is shown. These points along with other details such as time required, cost, and relation to favorable and unfavorable acreage, strongly recommend this method of exploring new ground under conditions such as prevail in Illinois.

JAS. H. HANCE.

THE VINTON, LOUISIANA, OIL FIELD

The following notes, written during the latter part of 1912, relative to the Vinton field, seem to the writer to contain items of geological interest bearing on Gulf Coastal development which are worth recording, particularly with reference to the lateral movement and induration of the oil sands. The notes are quoted with slight change from the form of which they were prepared some eight years ago. It is hoped that they will elicit other data bearing on the same subject which have no doubt come to light in the course of subsequent development.

An interesting instance of lateral movement in an oil sand has lately been noted in the Vinton field of southwestern Louisiana. On the west side of the pool, which at present comprises scarcely more than 70 acres, fifteen or more wells, all located within an area of perhaps 10 acres, for some obscure reason, got out of order. In nearly every instance the tubing parted when pulled, leaving a few joints in the hole, and the lower joint recovered was usually flattened. Upon investigation, it was found that the pipe in the bottom of the wells was either flattened or deflected sidewise. In one instance the pipe had been broken squarely off. A drilling rig was placed over this well, and after drilling through about 20 feet of tough gumbo, below the point where the pipe had parted, the lost section of pipe was struck, indicating that the top part had been shoved over into the wall of the hole. The wells all proved to be in such bad shape that they were without exception lost.

Movement of the oil sand and of the overlying formation was evidently responsible for the trouble. That the movement was not uniform, and did not affect the sand as a body, is evident from the fact that there are yet unaffected producing wells in the midst of those lost. As to the direction of movement, nothing is known; from the fact that there are yet unaffected producing wells in the midst of those lost. As to the direction of movement, nothin gis known; nor has the amount of lateral displacement been determined further than that it was sufficient to ruin the wells by shearing off the pipe, both casing and tubing.

Another feature to cause considerable comment among the producers of the field has been apparent hardening or induration of the top of both the 2000 and the 2350 foot oil sands. These sands were each found to be uniformly soft and unconsolidated when first penetrated. After an interval of two or three months,—long enough for other nearby wells to be

drilled to the necessary depth—the top of the sand was found to be very hard,—"crystallized" as expressed in the vernacular of the drillers,—although below a few feet the sand was unconsolidated and produced oil. It seems unlikely that soft spots should accidentally have been penetrated by the first wells finished in each sand, and subsequent wells should almost invariably find the top of the sand hard; hence it seems probable that some process of induration set in after the sands were tapped. These wells usually showed a very high gas pressure and flowed violently when brought in.

The two sands vary greatly in thickness within short lateral distances, having a maximum thickness of over 100 feet in several instances. The temperature of the oil from the 2000 foot sand at first tested 100 degrees F. or over, being so hot that the hand could with difficulty be held on the flow lines; but the heat gradually subsided to normal as production decreased. There was no accompanying invasion of salt water as the production from this sand declined. Evidently the unusual heat was due to friction owing to the violent flow. The temperature from the subsequently discovered deeper sand was never noticeably above normal, and recently several of the larger wells finished in it have been producing increasing quantities of water.

An interesting field of speculation is opened up in seeking the cause of unusual temperatures freuently found in the oil of the Gulf Coastal fields. Hot oil is by no means a novelty in the Coastal region, but the causes of the heat are imperfectly understood,—in fact are not understood at all. Temperatures as high as 125 degrees F were recorded at Batson and almost as great heat was noted at Anse la Butte, La., and Markham, Texas. Almost without exception, however, the high temperatures presaged a sudden influx of salt water and a slump in production. What causes the heat? Is the oil hot in its original state in the sand? or does some heat-producing chemical reaction set in when water is first admitted to the oil sand?

It might be added that the writer subsequently formulated some definite ideas with reference to oil temperatures which were submitted in writing to DeGolyer and were quoted by him in his paper on Mexican Oil Field Temperatures (Econ. Geol., June, 1918).

W. E. WRATHER.

AT HOME AND ABROAD

MR. A. A. HAMMER is now in charge of the exploratory work for the Absaroka Oil Development Company, with headquarters at Billings, Montana.

MR. J. B. TEMPLETON has returned from a stay of fifteen months in Palestine to Cosden & Company. He reports that the British authorities in Palestine and Mesopotamia permit no geological or archeological work by Americans and that A. Beebe Thompson is in charge of geological work for the British Government.

MR. H. A. LEY has also returned from Palestine and is now with the Sun Company in Dallas.

MR. J. Y. SNYDER, the veteran geologist of Shreveport, discovered the Haynesville structure on which Smitherman, Palmer et al recently brought in their large well in sec. 14, T. 23 N, R. 8 W. Oklahoma, offsetting the dry hole drilled by the Roxana Petroleum Corporation. It was through the efforts of Mr. Snyder that the old well was cleaned out, and a good show of oil and gas found during this work. Mr. Snyder is to be congratulated on his remarkable success in securing a thorough test of the structure and for his business acumen in securing one-eighth interest besides royalty rights in the block of sixteen sections surrounding the well. This appears to be the greatest single financial success ever attained by a geologist.

MR. E. EGGLESTON SMITH, who has been in charge of operations in Algeria for the Whitehall Petroleum Corporation (Pearson interests) is returning to the United States.

MR. C. L. SEVERY has opened an office as consulting geologist at 727 Kennedy Bldg., Tulsa, Oklahoma.

MR. A. C. VEATCH has recently been on a trip to Central America.

MR. C. O. DOUB is engaged in tax work at 316 Wheeler-Kelly-Hagny Bldg., Wichita, Kansas.

MR. E. W. SHAW has resigned from the U. S. Geological Survey and is engaged in professional work.

MR. S. C. HEROLD is reported to be engaged in foreign work. His address is 5729 Holden Street, Pittsburgh, Pa.

OKLAHOMA UNIVERSITY has produced many geologists and holds the record for making them by families,—three from the Burress and three from the Clark family.

MR. PAUL V. ROUNDY of the U. S. Geological Survey recently completed field work in the Osage which will be published as a chapter of Bulletin 686.

MR. J. E. HOOVER of Kirk and Hoover, Tulsa, is in Mexico.

MR. RALPH HOWELL, formerly with the U. S. Geological Survey, was killed in India by tribesmen in December, while engaged in exploratory work.

DR. IRVING PERRINE is President of the newly organized geological society of Oklahoma City. The other officers are Harve Loomis and L. E. Trout.

MR. O. B. HOPKINS, Chief Geologist of the Imperial Oil Company of Toronto, Canda, is in Columbia.

MR. F. K. FOSTER is Chief Geologist of the White Eagle Oil & Refining Company, Wichita, Kansas.

MR. H. H. ADAMS has opened an office at Duncan, Oklahoma. Mr. Adams is credited with the location of the Parsons & Gent gusher, Thomas No. 1, sec. 25, T. 1 N., R. 9 W. Oklahoma.

DR. J. L. RICH is now in charge of geological work in the Rocky Mountains for the Gypsy Oil Company.

MR. N. C. ADAMS located the large well of Wilcox and Oswalt in sec. 20, T. 18 N., R. 10 E., west of Sapulpa, Oklahoma. This well is on a small anticline in the midst of the faulted zone which extends from Bristow to the Osage.

DR. J. C. BRANNER has recently been engaged in professional work in Arkansas.

MR. F. B. ELY is in northern Mexico, his address is care Laredo Nat'l. Bank, Laredo, Texas.

MR. ARTHUR EATON has recently opened an office with Mr. James L. Darnell in New York City.

MR. J. E. BRANTLEY is with the Sun Company, in Mexico.

MR. W. C. SPOONER is in the Orient. E. W. Scudder is temporarily in charge of the geological department of the Arkansas Natural Gas Co. in Tulsa during the absence of Mr. Spooner.

MR. S. K. CLARK is associated with the Arkansas Natural Gas Company in Tulsa.

The Gardner-Spencer Company, of Tulsa, has become the Gardner Petroleum Company with Mr. Jas. H. Gardner, President.

MR. BURTON HARTLEY has moved his office to 206 So. Cheyenne, Tulsa.

MR. J. E. HOOVER is spending a year in Mexico.

MR. ARTHUR IDDINGS is in Tampico.

MR. HUNTSMAN HAWORTH discovered the structure in sec. 6, T. 27 S. R. 8 E., Butler county, Kansas, upon which a successful well has been completed in the Burgess sand at a depth of about 2700 feet.

MR. JERRY BURNETT, formerly of the Empire Gas & Fuel Company, now a graduate student at the University of Nebraska, discovered the anticline

in sec. 24, T. 21 S., R. 10 E. where the Super Six Oil Company completed a hundred barrel well of 19° Baume oil.

MR. L. B. SNIDER is with the Amerada Petroleum Corporation with headquarters at Tulsa.

MR. C. M. DORCHESTER is in Mississippi as scout and geologist for the Gulf Production Company.

MR. L. J. YOUNG is Chief Geologist of the Oklahoma Producing and Refining Corporation.

MR. S. W. WELLS has opened an office as consulting geologist at Okmulgee.

MR. L. E. KENNEDY makes his headquarters at Muskogee.

PROF. SAMUEL WEIDMAN, of Norman, Oklahoma, has made arrangements to analyze oil sands on a commercial basis.

MR. A. F. TRUEX represents the Invincible Oil Company interests at Tulsa.

MR. L. W. STEPHENSON has recently been engaged in oil work in Mexico.

MR. BEVERLY TATUM mapped the structure in sec. 3, T. 35 S., R. 5 W., Cowley county, Kansas, upon which a small well has recently been completed. Mr. Tatum is at present in Mexico with the Mexican Eagle Oil Company.

MR. H. S. RADE mapped a structure for the Arkansas Natural Gas Company in sec. 7, T. 32 S., R. 5 E., Cowley county, Kansas, upon which an oil well has recently been completed.

MR. A. P. WRIGHT is now President of the Riverland Company.

MR. E. H. BAUMAN is geologist for the Oklahoma Petroleum & Gasoline Company at Graham, Texas.

MR. S. S. PRICE, now associated with F. H. Wickett, in Tulsa and Shreveport, was instrumental in selecting the properties for the Dixie Oil Company at Pine Island, Louisiana, on which large production was obtained several years ago. Last year Dillon No. 29 in the NE¼, NE¼, sec. 14, T. 21 N., R. 15 W., was drilled to a Lower Cretaceous sand, probably at the horizon of the Kiamichi clay, and was recently deepened in the sand to 2790 feet. It now produces 800 bbls. daily of oil 44° gravity. This is the first well in the United States to produce oil in commercial quantity from the Lower Cretaceous. A number of gas wells in East Texas and Louisiana near Bethany produce gas from approximately the same horizon.

MR. BEN BELT is believed to be responsible for the location of the large anticline in Carson county, Texas, north of Panhandle, on which the Gulf Production Company has a gas well and another well showing oil.

MR. PIERCE LARKIN is credited with locating the Robberson, Oklahoma, gas field. He also located the Boynton field opened in 1914 which covers a large portion of T. 14 N., R. 16 E.

Mr. C. D. Smith mapped the Deer Creek anticline upon which the Western States Oil Company completed a well in sec. 14, T. 27 N., R. 3 W., Grant county, Oklahoma.

Mr. Forest R. Rees is Chief Geologist for the Skelly Oil Company in Tulsa.

Mr. W. R. Longmire is now with the Pierce Oil Corporation in Oklahoma City and is working in Duncan.

Mr. A. E. Stander is division geologist for the Texas Company in Tulsa.

Mr. Joe Kupperstein of the Texas Company will go to Venezuela to join L. A. Scholl, Jr., Chief Geologist.

Mr. C. D. Johnson has opened an office in Kansas City at 720 Commerce Bldg. Mr. Johnson will drill an anticline in Missouri north of Kansas City.

Mr. Richard Hughes mapped the anticline in sec. 15, T. I S., R. 8 W., Stephens county, Oklahoma, on which Cosden & Company have a well.

Mr. A. C. Reeds located the Kilgore well on the Doyle structure in sec. 11, T. 1 N., R. 5 W., Stephens county, Oklahoma.

Mr. G. F. Scott of Wichita, Kansas, is spending most of his time in Eureka where he is interested in several tests.

Mr. R. J. Riggs has moved his office to 211 Pan American Bldg., Tulsa.

Mr. W. J. Millard discovered the Hewitt anticline in southern Oklahoma in 1916. Last December he completed an 80 barrel well in the Wilcox sand at 1273 feet in sec. 20, T. 17 N., R. 17 E., Wagoner county, Oklahoma. The top of the Morrow was found at 600 feet and the normal succession of Pitkin, Fayetteville, Boone, and Chattanooga were passed through. The oil is produced from a depth of 200 feet in the Tyner formation of Ordovician age. This well is an interesting confirmation of the opinion that the Wilcox sand is of Ordovician age, this opinion having been arrived at independently by Fritz Aurin and Richard Hughes. The first recognized Ordovician production in Oklahoma was from the Simpson formation in the Healdton field and two wells now produce Ordovician oil in that field. Mr. Millard is now associated with New York parties and has his office at 226 Lynch Bldg., Tulsa.

Mr. J. H. Jenkins formerly of the Mid-Co. Petroleum Company has gone to Mexico for the Tidal Oil Company. Mr. J. V. Howell has taken his place at the Tidal office in Tulsa.

The Tulsa Geological Society recently elected C. T. Kirk, President, C. D. Smith, Vice-President, Richard Hughes, Secretary, and Frank Green, Treasurer.

The Tulsa section of the A. I. M. E. has elected M. M. Valerius, Chairman, Jon A. Udden, Secretary-Treasurer. An important meeting was held April 28th attended by the President and Secretary from New York.

PROCEEDINGS OF THE SIXTH ANNUAL MEETING
OF THE
AMERICAN ASSOCIATION OF PETROLEUM GEOOLGISTS HELD AT TULSA, OKLAHOMA, MARCH 17-19, 1921

The headquarters of the American Association of Petroleum Geologists during the sixth annual meeting were at Hotel Tulsa. The technical sessions were held in the audience room of the Tulsa Chamber of Commerce, in the Municipal Building, except the one of Thursday evening, which was held in the Grill Room in the Hotel.

The opening session was called to order by President Wallace E. Pratt, and greetings were extended to the Association by Frank H. Greer, Director of the Chamber of Commerce, and by George C. Matson, President of the Tulsa Geological Society. A response was given by President Pratt. Numerous excellent papers were presented in the technical sessions on some general subjects of geology as well as on the geology of the Mid-Continent Oil Fields, on the geology of nearly every important oil-producing state, and on the geology of Eastern Alberta, British Columbia, Venezuela, Peru, and Mexico. A most interesting series of illustrated papers were given Thursday evening by Earl Trager on Kerogen, W. R. Jillson on the Oil Shales of Kentucky, and David White on the Origin of Oil Shales, the latter being a particularly comprehensive and illuminating treatment of this important subject.

The general social features were the Smoker, following the session Thursday evening, and the annual subscription dinner, Friday evening. Dr. D. W. Ohern, the toastmaster, introduced as speakers, Hon. T. D. Evans, Mayor of Tulsa, Dr. I. C. White, J. Elmer Thomas, James Gardner, and Stanley Herold. The wives of the Tulsa geologists entertained the visiting ladies with a reception at the Country Club, and at a matinee at the Orpheum. A special feature on Saturday morning was a trip to the Cosden Refinery in charge of M. M. Valerius, Chairman of the local Arrangements Committee.

The business of the Association was transacted on Friday afternoon and Saturday morning with President Wallace E. Pratt as Chairman. The president reported that it had been the endeavor of the Executive Committee to bring the affairs of the Association more closely in touch with the Petroleum Industry; to strengthen the Bulletin; and to increase the membership of the Association. Dr. Charles E. Decker gave the reports of the Secretary-Treasurer which appear later in these proceedings. The Editor, Dr. Raymond C. Moore, reported that 1500 copies of Part I of Volume V had been published, and placed in the hands of the members. He recommended the publication of a Bulletin at regular intervals, which, in addition to the papers presented at the annual meeting, would contain discussions of those papers, abstracts and reviews of important contributions to petroleum literature, and personal items concerning mem-

bers of the Association. He stated that the Bulletin of 1920 had been published at the peak of high prices, and that arrangements could be made with the University of Kansas Press so that the larger number of parts would not increase the cost materially. He expressed the opinion that an income of from $500.00 to $600.00 could be secured in each part from advertising, and suggested that some copies of the Bulletin could be bound for those who should desire it in a more permanent form. The report of the Editor was adopted unanimously, and a vote of thanks and appreciation extended him.

The Committee on Constitution, Alexander Deussen, Chairman, James H. Gardner, George Clark Gester, C. W. Washburne and W. E. Wrather, presented the proposed constitutional changes, copies of which had been mailed to each member one month prior to the annual meeting. The more important changes were: that which outlined more definitely the object of the Association; (Article 11—Object) that which defined the privileges and restrictions of associate members; (Article III, Section IV, —Associates); that which added the retiring president to the executive committee; (Article IV, Section I,—Officers), and that which provided for future constitutional amendments. (Article VI—Amendments). The proposed amendment which provided for the election of honorary members was laid on the table. The report was adopted, with only a few minor changes.

The report of the Ways and Means Committee, R. W. Pack, E. DeGolyer, K. C. Heald, J. E. Thomas, and L. C. Snider, was read and referred to an auditing committee, composed of D. Donoghue, J. E. Thomas, and K. C. Heald. The recommendations were adopted that the report of the secretary-treasurer be accepted, that the secretary-treasurer, and editor be authorized to expend such money as may be necessary for conducting the business of the Association, not exceeding the income of the year, and that a new type-writer of standard make, and a steel letter file for the office of the secretary-treasurer be purchased.

The following recommendations of the General Committee were adopted.

1. The publication of the bulletin as outlined by Dr. R. C. Moore.

2. The payment of a salary for the Editor of $600.00 and expenses.

3. The appointment of a committee of from seven to eleven to cooperate with the U. S. Geological Survey in estimating the amount of national reserve petroleum resources, and informing the public of the seriousness of the reserve depletion.

4. The appointment of the legislative committee to whom all matters concerning legislation pertaining to the petroleum industry, or difficulties in procuring appropriations from the State or for the State Survey, shall be referred.

5. The appointment of a committee of three to cooperate with existing bureaus for the making of more complete maps.

7. The endorsement of the public works bill.

8. The annulment of the resolution of last year that a member should not advertise his membership in the use of the name of the Association on professional cards, advertisements, or reports.

Signed:

W. E. Wrather	*Max Ball*	*Sidney Powers*
D. W. Ohern	*Alexander Deussen*	*J. W. Gardner*
Roswell Johnson	*Leon Pepperburg*	*David White*
J. E. Thomas	*Stanley Herold*	*M. M. Valerius*
R. C. Conkling	*George C. Matson*	*Richard Hughes*
		Mowry Bates

The Committee on Resolutions presented the following report, which was adopted.

WHEREAS, it has become evident to the American Association of Petroleum Geologists that certain foreign powers have adopted toward American capital, a policy of rigid exclusion so far as rights to explore, acquire, and own oil properties within their boundaries or spheres of influence are concerned, and WHEREAS, it is a matter of common knowledge that the American Government grants to foreigners and foreign capital the same rights as are granted to American citizens, NOW THEREFORE, in the full realization of the duty of service, which this Association owes to its country, BE IT RESOLVED, that the American Association of Petroleum Geologists urge upon every member of our National Legislative bodies a prompt consideration of the serious situation which confronts the Nation, and the prompt enactment of whatever legislation may be required to insure to Americans and American interests rights in foreign fields, which shall be entirely equal in every respect to the rights which foreigners and foreign interests enjoy in American territory. (It was voted that a copy of this resolution be sent to each member of Congress, and that a copy be included in the next publication of the Association.)

BE IT RESOLVED, by the American Association of Petroleum Geologists, assembled in their annual meeting, that a memorial be prepared setting forth the biography of our late fellow member, Wilbur L. Moody, and furthermore stating the high esteem in which he was held by the Association, and the distinct loss which the Association and the entire profession suffer through his untimely death. BE IT FURTHER RESOLVED, that a copy of this memorial be published in the Bulletin of the Association, and sent to Mr. Moody's wife and mother, expressing our heartfelt sympathy and condolences over their recent bereavement.

BE IT RESOLVED, that the American Association of Petroleum Geologists extend to the Tulsa Chamber of Commerce, the Committee on Arrangements, the Ladies of Tulsa, the Tulsa Geological Society, and all those who have made this meeting the wonderful success it has been, their most cordial appreciation for their untiring zeal and earnest efforts in behalf of this Association.

Be It Further Resolved, that a copy of these resolutions be spread on the minutes of this meeting.

Signed, *A. L. Beekly,*
R. T. Hill,
Irving Perrine.

The following committees were appointed.

Program and Editorial Committee

Ralph Arnold, New York City.
K. C. Heald, Washington, D. C.
General
Roswell Johnson, Pittsburgh, Pa.
Appalachian Division
Jas. H. Hance
Central Western Division
Sidney Powers
North Mid-Continent Division
Frederic H. Lahee
Central Mid-Continent Division
Wallace E. Pratt
South Mid-Continent Division

Constitution Committee:

D. W. Ohern, Oklahoma City, Oklahoma
Alex W. McCoy, Bartlesville, Okla.
David Donoghue, Fort Worth, Texas.
Carl Beal, San Francisco, Calif.
Leonard G. Donnelly, New York City.

Ways and Means Committee:

Raymond C. Moore, Lawrence, Kansas.
R. W. Pack, Beaumont, Texas.
E DeGolyer, New York City.
J. Elmer Thomas, Chicago, Illinois.
C. W. Washburne, New York City, N. Y.

Membership Committee:

Ranson E. Somers, Pittsburgh, Penna.
Appalachian Division.
Frank W. DeWolf, Urbana, Illinois.
Central Western Division
Richard Hughes, Tulsa, Oklahoma.
North Mid-Continent Division
Fredric H. Lahee, Dallas, Texas.
Mid-Continent Division
Eugene Holman, Shreveport, Louisiana.
South Mid-Continent and Gulf Coast Division
Wallace Lee, Denver, Colorado.
Rocky Mountain Division

R. E. Collom, Berkley, California.

Pacific Coast Division

ETHICS COMMITTEE:

Roswell Johnson, Pittsburgh, Penna.
Alexander Deussen, Houston, Texas.
E. D. Nolan, San Francisco, California.

LEGISLATIVE COMMITTEE:

Irving Perrine, Oklahoma City, Okla.
L. P. Garrett, Houston, Texas.
W. H. Twenhofel, Madison, Wisconsin.
C. W. Studt, Yates Center, Kansas.

MAP COMMITTEE:

J. B. Umpleby, Norman, Oklahoma.
A. C. Veatch, New York City, N. Y.
C. M. Bennett, Shreveport, Louisiana.

PUBLICATION COMMITTEE:

C. H. Taylor, Oklahoma City, Okla.
Eliot Blackwelder, Denver, Colorado.
H. B. Goodrich, Tulsa, Oklahoma.

COOPERATIVE COMMITTEE:

The following men are chairmen of the respective regions:

Roswell H. Johnson—New York, Pennsylvania, West Virginia, and Eastern Ohio.
L. C. Glenn—Kentucky, Tennessee and Paleozoic areas in Oklahoma and Mississippi.
Frank W. DeWolf—Ohio, Indiana, Illinois and Missouri.
A. W. McCoy—Kansas.
Mowry Bates—Oklahoma.
W. E. Wrather—Northern and Central Texas.
Alexander Deussen—Southern Texas.
W. E. Hopper—Arkansas, Louisiana, Mississippi and Alabama.
C. T. Lupton—Rocky Mountain States on both sides of the continental divide from the Canadian to the Mexican border.
Carl H. Beal—California, Oregon, and Washington.
K. C. Heald—All other states.

INTERNATIONAL RELATIONS COMMITTEE:

A. C. Veatch, New York City, N. Y.
Ralph Arnold, Los Angeles, Calif.
Wallace Pratt, Houston, Texas

The officers elected for the coming year are:

PRESIDENT—GEORGE C. MATSON, Tulsa, Oklahoma.
VICE PRESIDENT—GEORGE CLARK GESTER, San Francisco, Calif.
SECRETARY-TREASURER—CHARLES E. DECKER, Norman, Oklahoma.
EDITOR—RAYMOND C. MOORE, Lawrence, Kansas.

These four together with Wallace E. Pratt, the retiring President, constitute the Executive Committee.

AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
REPORT OF THE SECRETARY

March 18, 1921

Number of Members March 15, 1919	210
Number of Members elected at Dallas, 1919	87
Number of Members at close of meeting 1919	297
Number of Members at meeting March 18-20, 1920	392
Number of Members elected at meeting March 18-20, 1920	81
Number of Members at close of meeting 1920	473
Number of Active Members March 15, 1921	536
Number of Associate Members March 15, 1921	85
Total Members March 15, 1921	621
Total applicants	53
Number withdrawn	6
Number dropped non-payment of dues (three years)	2
Number died	7
Active members in arrears for 1920 dues	14
Active members in arrears for 1921 dues	192
Associate members in arrears for 1921	38
Total members in arrears for 1921	230

Respectfully submitted,

CHARLES E. DECKER,
Secretary.

AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
REPORT OF TREASURER

March 18, 1921

Balance in bank March 18, 1920				$ 926.89
Receipts to March 17, 1921				
Dallas luncheon and dinner				793.00
Annual dues	1921	$3,861.00		
	1920	3,572.00		
	1919	35 00		
	1918	15.00		
Total annual dues		———		7,483.00
From sale of bulletins				
	1920	$202.00		
	1919	410.10		
	1918	258.00		
	1917	255.00		
Not itemized		29.00		
Total sales from bulletins		———		1,154.00
Separates from 1919				44.00
			Total receipts	10,400.99

Disbursements			
Expenses of Dallas meeting			
Badges	$ 99.28		
Programs	13.60		
Reporting	250.70		
Luncheon	382.50		
Dinner	450.00		
Entire expense of meeting	——		1,196.08
Cost of bulletins, 1920	$3,637.01		
Engraving, 1921 bull.	52.03		
Binding, 1918 and 1919	210.00		
Total expense of bulletins			3,899.04
Questionaires prepared. Prof. Directory			
Salary of secretary treasurer			
1919	$ 500.00		
1920	600.00		
Stenographer, Miss Van Horn	106.43		
Assistant in mailing	1.50		
Total for salaries			1,207.93
Supplies and printing			226.32
Postage			145.33
Checks, returned and protested			82.29
Telegrams and cable message			24.86
Drayage and express			15.73
Travelling expenses			12.65
Refunds			8.00
		Total disbursements	6,818.23
Balance in open account	$1,504.18		
Deposited March 14	98.95		
In savings account	2,000.00		
Beeby Thompson check	10.00		
	3,613.13		
Outstanding checks	30.37		
	3,582.76		3,582.76
			$10,400.00

Respectfully submitted,
CHARLES E. DECKER
Treasurer.